CHAPTER EIGHT

The Bay's Living Resources

Ah, my dear friend, would that you were here just now to see the snipes innumerable, the blackbirds, the gallinules, and the curlews that surround us;—that you could listen as I now do, to the the delightful notes of the mockingbird, pouring forth his soul in melody as the glorious orb of day is fast descending towards the western horizon;—that you could gaze on the great herons which, after spreading their broad wings, croak aloud as if doubtful regarding the purpose of our visit to these shores!

–John James Audubon, upon visiting Galveston Bay in 1837

Galveston Bay is home to a myriad of organisms that live in a variety of estuarine habitats and which interact with the bay in a variety of ways. Fish and wildlife resources provide some of the Bay's greatest values, economically, recreationally, and aesthetically. Individual species, ranging from microbes to alligators, can also serve as useful indicators of the overall condition of the ecosystem; therefore considerable scientific and regulatory resources are devoted to studying their populations. Quite naturally, most monitoring efforts are directed at the species of greatest concern to humans–particularly seafood species.

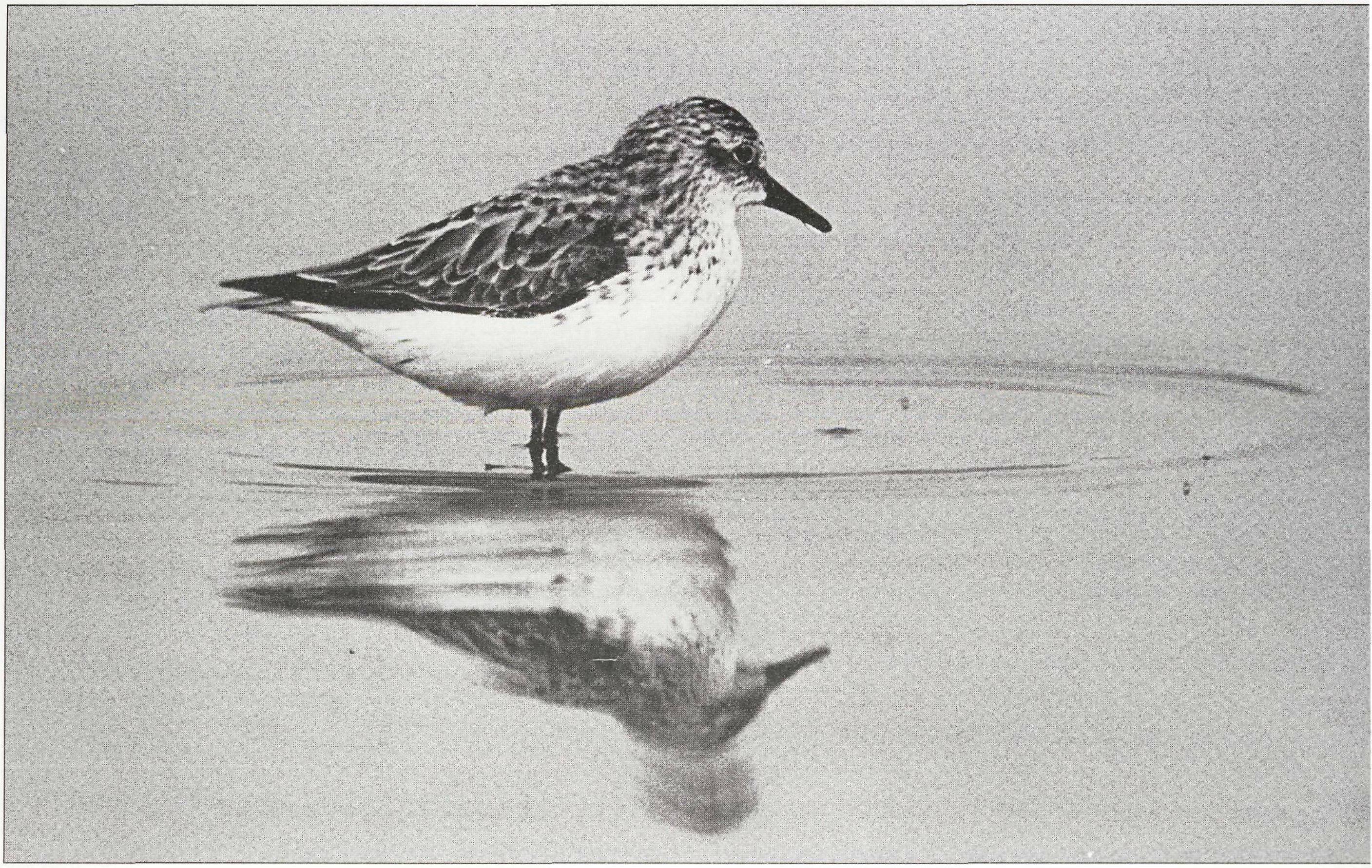
Historical accounts indicate that several Galveston Bay fish and wildlife species, including sea turtles, snook, striped bass, and the saltwater terrapin, have either disappeared or declined dramatically in the last 150 years. This provides reason for concern about conditions in the bay causing these declines–are these conditions likely to cause declines in other species? On the other hand, long-term commercial and recreational fishing harvest records (some dating back to the 1890s) show harvest fluctuations over time, but no dramatic species decline (see seafood landings in Chapter Four).

Based on a major review of living resources in the estuary (reported in this chapter), the Texas Parks and Wildlife Department concluded that the overall "health" of the bay system is fair to good. There were no observed wholesale declines in species population abundance over the past ten to 20 years and the energy and material transfers throughout the food web were occurring more or less naturally (Green et al., 1992). In fact, there were significant increases in some populations, including American alligator, red drum, spotted seatrout, Atlantic croaker, black-bellied plover, willet, sanderling, western sandpiper, olivaceous cormorant, and brown pelican. To now, Galveston Bay has clearly escaped major biological losses seen in some of the Atlantic estuaries.

Recent trends for several bay species, however, do raise concerns. Population declines have been observed over the past decade for white shrimp, blue crab, mottled duck, and some shoreline-feeding birds. The major decline in submerged aquatic vegetation and 17–19 percent loss of estuarine wetlands described in Chapter Seven are troublesome issues; estuarine species that depend upon these key habitats could be affected if these trends continue (Green et al., 1992). As these habitats have declined, fishing activity and recreation usage of the bay continues to increase, placing added strain on the resource.

This chapter summarizes findings from several recent studies of the bay's living resources. Discussion begins with a description of the bay's food web, a concept that reveals the interdependence among bay species and the importance of external materials and processes to estuarine species populations (see also Chapter Three). Major taxonomic categories in the food web are considered in separate sections, beginning with the base of the food chain and progressing to higher levels: phytoplankton, zooplankton, benthic organisms, oysters, finfish, shrimp and crabs, birds, amphibians and reptiles, and finally, mammals. Objective data on most of these topics is of recent vintage, rarely predating the 1970s. Therefore, we lack a larger historical perspective on the findings reported here.

Much of the material in this chapter falls in the realm of population dynamics. What controls the population size of a given



Source: Frank S. Shipley

A semipalmated sandpiper surveys the placid waters of a mud flat.

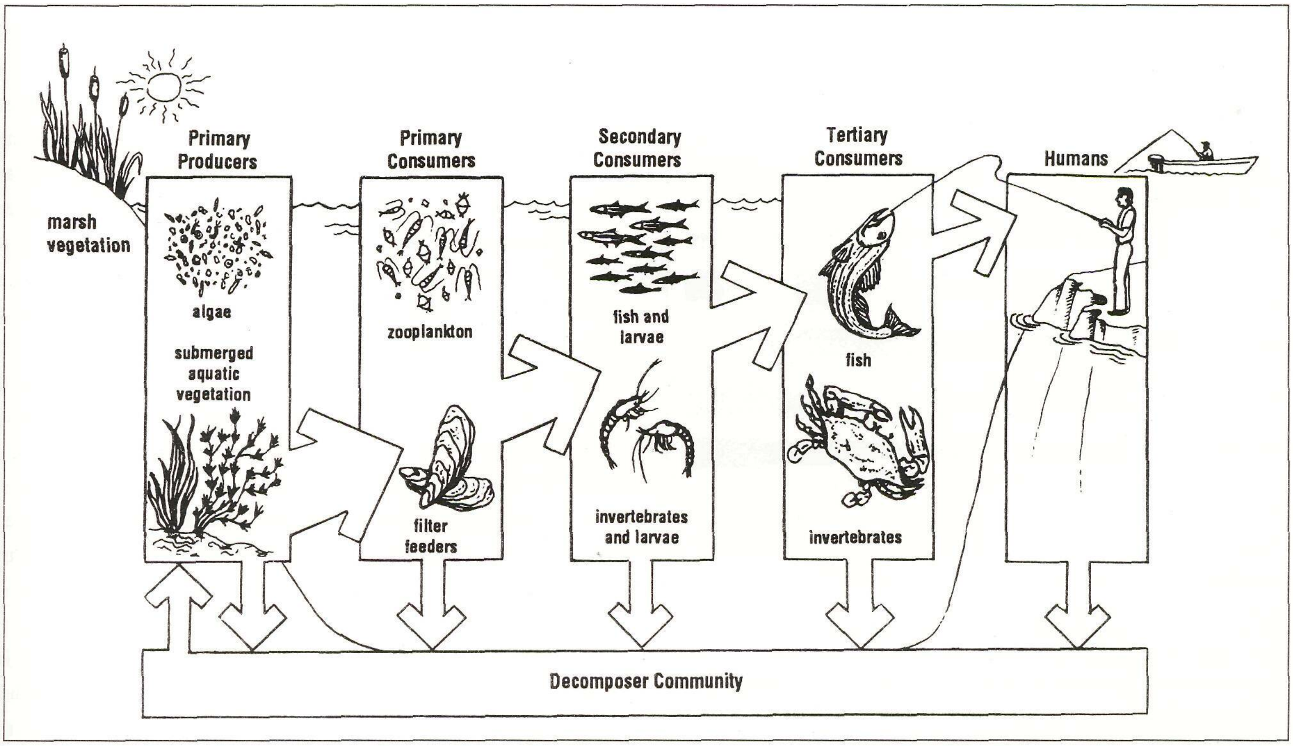
species? Among the relevant factors are habitat (both quantity and quality) degree of environmental contamination, and a host of natural forces such as predation, competition for food or space, diseases and parasitism. Population regulation can be controlled seasonally; it can also operate on just one of several life stages. While estuarine populations may frequently be limited by abiotic factors of the physical environment (hurricanes; salinity), this is not an unswerving rule; most often, the underlying mechanisms remain hidden. Therefore, managers of estuarine populations (who are responsible for species management regardless of how much is understood) work with the tools available, including harvest regulations for commercial and recreational species, habitat protection, and actions to keep the environment free from contaminants. Trial and error can help determine management actions that work for a given species, while science continues to search out the underlying mechanisms.

THE ESTUARINE FOOD WEB

The estuarine food chain has been described by Monroe and Kelly (1992):

> *Life in an estuary does not happen in random order; rather, it is organized and structured. From the simplest microscopic plants to the largest animals, organisms are connected to each other in chains of "who eats whom" known as a food web.*
>
> *In a food web, plants and animals are connected by energy flow. At the bottom of the web, green plants and some bacteria utilize the energy of sunlight to combine carbon dioxide and water into simple foods. In this process known as photosynthesis, plants and photosynthetic bacteria convert or "fix" inorganic carbon into molecules of carbohydrates. In doing this, they store the energy of sunlight in organic chemical bonds. As small animals consume these plants and bacteria and are in turn eaten by predators, the energy passes through the food web.*
>
> *Plants and photosynthetic bacteria are known as primary producers in a food web because they produce the first forms of food. Animals that eat plants are known as primary consumers, and animals that eat other animals are called secondary or tertiary consumers.*

Some of the paths of energy flow in a typical estuarine food web are depicted in simplified form in FIGURE 8.1.



Source: Alliance for Chesapeake Bay, 1992

FIGURE 8.1. The estuarine food web begins with solar energy converted to green plant tissue. As grazers, the primary consumers use this tissue directly, in turn supporting predators at several levels. An important part of this system is the detrital pathway; decaying organic matter originating at each step supports a diverse group of decomposers.

Primary Production

The various levels in the food web all ultimately rely upon energy captured from the environment by green plants, the primary producers. In Galveston Bay, there are six main primary producer communities ranging from phytoplankton (algae) in open bay habitat to trees and perennials in woodlands and swamps bordering the estuary (TABLE 8.1). Each of these flora types is responsible for a portion of the production (generation of organic matter through photosynthesis) that sustains primary consumers and their predators.

Sheridan et al. (1989) used literature values to estimate primary production for six main classes of flora, and concluded that phytoplankton, benthic microflora, plants in salt and brackish marshes, and trees in woodlands and swamps all contribute roughly the same order of magnitude of organic food to the estuary. Fresh water marshes were a much smaller contributor. Although submerged vegetation had the highest productivity per square kilometer, their small areal extent in the bay made them less significant in terms of the amount of fixed energy produced. A good deal of uncertainty is involved in making these estimates.

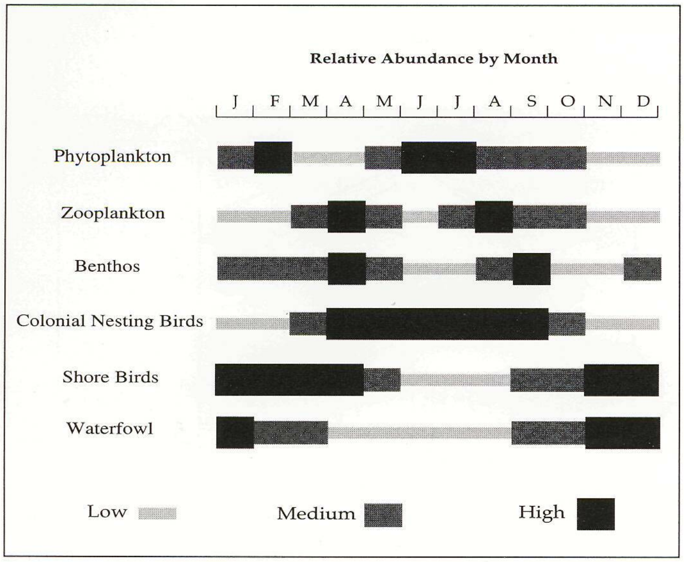
TABLE 8.1. Primary Productivity in the Galveston Bay System.

Flora	Average Estimated Primary Productivity (g dry/m^2/yr)	Areal Coverage (km^2)	Estimated Annual Production (metric tons)
Phytoplankton	350	1,425	498,750
Benthic microflora	500	1,425	712,500
Submerged vegetation	2,600	1	2,600
Fresh water marsh	820	40	32,800
Salt-brackish marsh	1,100	370	407,000
Woodlands/swamps	700	500	350,000

Source: Sheridan et al., 1989

Much of the primary production identified by Sheridan et al. is separated in time and space from the primary consumers. For example, woodlands, swamps, and fresh water marshes probably export less than ten percent of their primary productivity to in-bay consumers because of their relative isolation, whereas salt water marshes may export 35-40 percent (Texas Department of Water Resources, 1981; Gosselink et al., 1979). In addition, the nutritional quality of the primary production is lowest for higher-order plants in marshes, swamps, and seagrass meadows, and highest for phytoplankton.

Because a substantial amount of the overall productivity reaching the estuary is of lower quality, the majority of the primary consumers in the bay system are species that consume the detritus of primary production rather than living plant material. Many of these species also consume the bacterial and fungal decomposers associated with decaying organic matter. These detritivores include many benthic organisms such as marine worms, bivalves, gastropods, crustaceans, and bottom feeding fishes and **macroinvertebrates** (Sheridan et al., 1989; Gosselink et al., 1979).



Source: Sheridan et al., 1989

FIGURE 8.2. *Living things at all levels in Galveston Bay's food web vary in abundance with the seasons. Seasonal reproduction patterns and species movements (for example juvenile shrimp migrating to the Gulf of Mexico) are the basis for much of the variability. These abundance patterns represent evolutionary adaptations to the dynamic processes of the estuary.*

Although the overall level of primary production contributed by marshes and phytoplankton is similar, there is conflicting evidence about which is more important as an energy base. Sheridan et al. (1989) presented three reasons why marshes may be more important: 1) zooplankton in the bay generally occur in low densities, indicating a relatively low level of direct grazing on phytoplankton (Texas Department of Water Resources, 1981); 2) Texas salt marshes are very productive of herbaceous matter when compared to marshes in other Atlantic and Gulf Coast states (Turner, 1976); and 3) many bay species grow up to be omnivores or carnivores, relying upon phytoplankton only in their larval stages (Gosselink et al., 1979). On the other hand, Armstrong (1987) concludes that only five percent of the carbon and primary nutrients in Galveston Bay originate from peripheral marshes. More research is needed to resolve this conflicting data.

Indicator Species

Food web theory provides a context for selecting particular **indicator species** at different trophic levels to indicate the overall condition of the ecosystem. "Indicator species" can be chosen to help evaluate particular environmental conditions (for example, degraded water quality), or they can be chosen as representative of a class of species with similar trophic roles. This chapter considers a spectrum of indicator categories with an eye to generalized evaluation of the bay ecosystem. These categories are:

> Primary producers. These include phytoplankton (free-floating algae), benthic microflora (microscopic bottom-dwelling plants), and higher plants which comprise the habitats discussed in Chapter Seven: seagrass meadows, marshes, and other wetlands.
>
> Primary consumers (including detritivores). These graze on the phytoplankton, bottom dwelling microflora, and detritus; they include microscopic floating zooplankton and benthic invertebrates. Some benthic invertebrates are good environmental indicators of contaminated sediments and stressed environments.
>
> Economically important groups generally utilizing middle trophic levels. These include finfish and most shellfish. Example species include red drum, sand seatrout, Atlantic croaker, southern flounder, white shrimp, brown shrimp, and blue crab.
>
> Species of special interest including top carnivores such as dolphins, sharks, and waterbirds; abundant prey species; and endangered species.

Species within each of these categories are marked by variability occurring on different time scales. One important scale is seasonal (FIGURE 8.2); many species are migratory or time their reproduction based upon seasonal water temperatures or food supplies. Investigations focusing upon population dynamics must account for this source of natural variability, before long-term trends relating to changing bay conditions or human activities can be deciphered. One key challenge to biologists is obtaining a long enough data record to partition the various sources of variability affecting species numbers.

PHYTOPLANKTON

Phytoplankton are microscopic single-celled algae that drift with the motion of the currents, constituting an important and high-quality source of energy to consumers. Problems can result from large changes in phytoplankton abundance. For example, excessive reproduction of phytoplankton, usually caused by enhanced levels of nutrients, results in algae blooms. Algae blooms can exert high oxygen demand on the water through nocturnal respiration and decomposition following death (in the daytime, algae are net producers of oxygen, as a by-product of photosynthesis). The oxygen depletion accompanying eutrophication can suffocate other aquatic organisms and generally degrade the environment. Conversely, a shortage of phytoplankton depletes the food supply of primary and higher consumers such as oysters, shrimp, fish, and birds.

Phytoplankton research in Galveston Bay began in the late 1950s and peaked in the 1970s with Trinity Bay impact studies related to cooling water discharges of the Cedar Bayou electrical power generating station. Key studies include Hohn (1959), Armstrong and Hinson (1973), Strong (1977), and Zotter (1979). Research on phytoplankton biomass includes Zein-Eldin (1961), Strong (1977), Mullins (1979), Krecji (1979), and Smith (1983). The Texas Department of Water Resources studied phytoplankton as part of a fresh water inflow study (1981). Most of these studies had limited spatial and temporal coverage, and no documented phy-

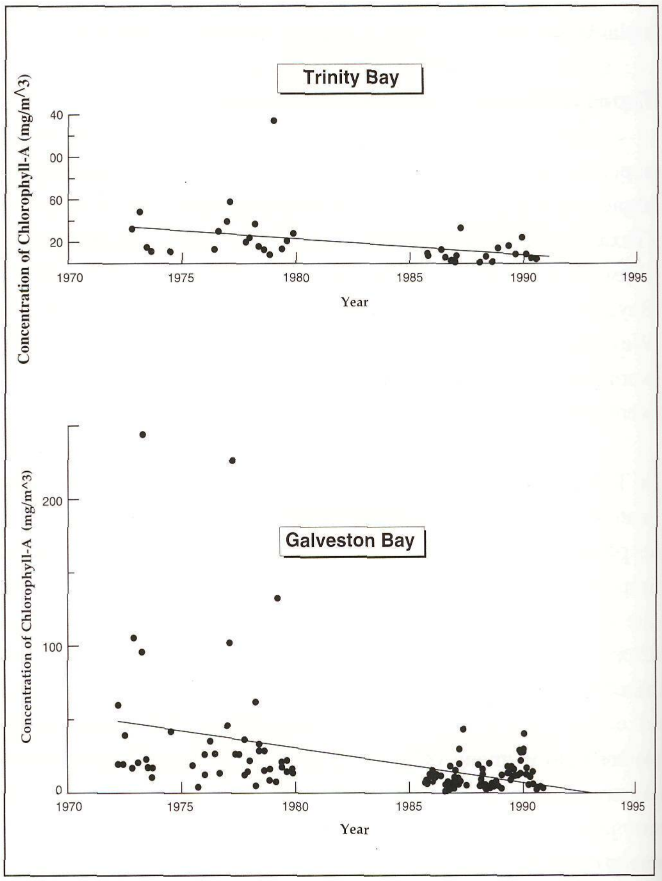
Concerning temporal trends, Buskey and Schmidt noted the difficulty in drawing long-term conclusions about phytoplankton abundance patterns. Several short-term phytoplankton studies, extending over a one or two-year period, evaluated temporal changes in phytoplankton abundance using chlorophyll-*a* as an indicator of biomass. In one early study, Zein-Eldin (1961) found no seasonal trend in average biomass at several Galveston Bay stations after taking chlorophyll-*a* samples once a week for a 20-month period in the late 1950s (FIGURE 8.3). Of note is the fact that several years of extreme drought ended in the middle of 1957, followed by higher flow in late 1957.

Possible Increases, 1950s–1970s

There is some indirect evidence of an increase in chlorophyll-*a* from the late 1950s to the 1970s (Buskey and Schmidt in Green, 1992). *Mean* chlorophyll-*a* concentration from the Zein-Eldin study in the late 1950s was 16 mg/m^3, which compares closely to an overall mean of 13 mg/m^3 and 17 mg/m^3 for stations in Trinity Bay measured by Mullins (1979) and Strong (1977), respectively. However, the *maximum* concentration of chlorophyll-*a* from the 1950s Zein-Eldin study was 45 mg/m^3, compared to higher maximum concentrations measured in three Trinity Bay studies in the 1970s: 70 mg/m^3 (Mullins, 1979), 120 mg/m^3 (Krecji, 1979), and 85 mg/m^3 (Strong, 1977). Smith (1983) found a maximum concentration of 45 mg/m^3 chlorophyll-*a* in the late 1970s.

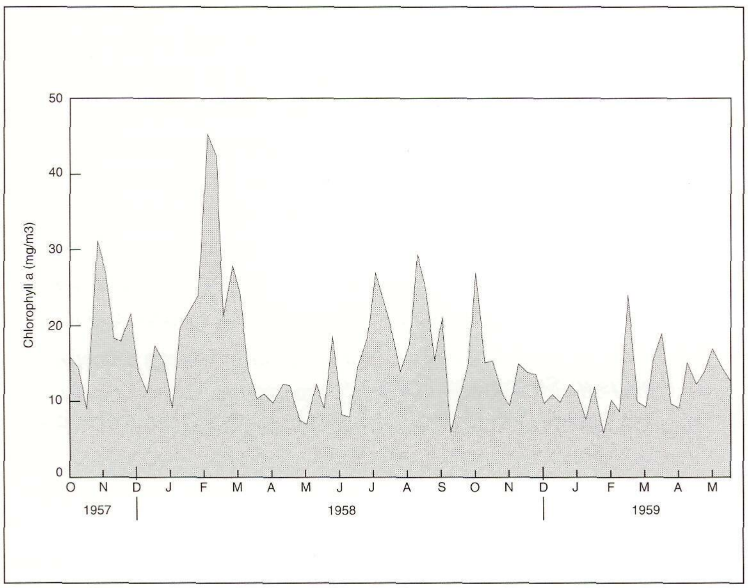
Declines, 1970s to Present

Since the 1970s, however, the existence of a routine monitoring program for chlorophyll-*a* has allowed better trend analyses,



Source: Ward and Armstrong, 1991

FIGURE 8.4. Chlorophyll-a, an indicator of phytoplankton biomass, has declined throughout much of Galveston Bay since the early 1970s. Data are shown for Trinity Bay and central Galveston Bay. A leading hypothesis for this reduction is reduced nutrients (particularly nitrogen) resulting from improved wastewater treatment and creation of reservoirs on the Trinity and San Jacinto Rivers.



Source: Zein-Eldin, 1961

FIGURE 8.3. Chlorophyll-a variation in Galveston Bay over a two-year period in the late 1950s. Phytoplankton abundance, indicated by chlorophyll measurements, is marked by unpredictable variability in short-term studies. Chlorophyll-a apparently increased (from the values shown here) to higher levels in the early 1970s, followed by a decline (FIGURE 8.4). Wind mixing and low water clarity tend to forestall seasonal algae "blooms" more frequent in some other U. S. estuaries.

even though this parameter remains merely an indicator of actual phytoplankton biomass. A clear decline emerged from analysis of this data by Ward and Armstrong (1992): mean chlorophyll-*a* concentrations fell by about 50 percent throughout much of the bay from 1969 to 1990 (see FIGURE 6.8b). This decline occurred in numerous individual hydrographic segments; data from lower Galveston Bay and from Trinity Bay are given in FIGURE 8.4. For each of these segments, mean chlorophyll-*a* from the 1970 to 1980 period was 30-35 mg/m^3, compared to ten to 15 mg/m^3 for 1985 to 1991.

This is a considerable decline in phytoplankton, but falls short of a precipitous "crash" to unmatched lows. Rather, implications of the chlorophyll measurements are that phytoplankton biomass may have reached levels slightly lower than values typical of Galveston Bay from 1957 to 1959. Current phytoplankton conditions are only slightly lower than the mean value observed during the late 1950s by Zein-Eldin.

Probable Causes of Trends

Why did phytoplankton apparently increase from the late 1950s to the early 1970s, then decline from the early 1970s to the resent? The complex dynamics of phytoplankton, combined with he lack of long-term direct measurement data makes the explana-ions discussed below somewhat speculative.

Buskey and Schmidt (in Green et al., 1992) suggested the arlier increase may have been caused by a combination of increas-ig nutrients and a change in predator populations. An increase in utrient concentrations from the 1950s to 1970s probably resulted rom increased point and nonpoint source discharges as the Iouston metro area developed. Buskey and Schmidt reported that ialveston Bay had lower zooplankton abundance than other Texas ays in the 1970s (see zooplankton section, below) and speculated link to "industrial discharges." If their hypothesis is correct, then nprovements in industrial discharges after 1970 could have llowed a resurgence in zooplankton populations, which subse-uently increased phytoplankton grazing. Unfortunately, not iough data are available to confirm the posited temporal change in ooplankton populations (Buskey and Schmidt in Green et al., 992).

Ward and Armstrong (1992) evaluated several potential uses for the decline in chlorophyll-*a* observed after 1970:

Declining inorganic nutrient supply

Increased toxicity or adverse environmental conditions

Increased predation on phytoplankton

Decreases in chlorophyll-*a* dominated organisms

Laboratory artifacts, due to alterations in methodology

They concluded nutrient reduction was the most plausible planation. Chlorophyll-*a* declines paralleled an observed 50 per-nt reduction in nutrients due to curtailed point source loadings in e early 1970s, the trapping of Trinity River nutrients due to con-uction of Lake Livingston in the early 1970s, and changes in land e in the upper watershed (see Chapter Six).

Finally, the decline in phytoplankton might be influenced by increased population of filter-feeders such as oysters or clams. selected areas of San Francisco Bay, the unintentional introduc-n of the Asian marine clam *Potamocorbula amurensis* resulted a phenomenal ten-fold reduction in phytoplankton levels in two ars (Monroe and Kelly, 1992). While this clam is not found in lveston Bay, Powell et al. (1994) identified "substantially high-' oyster reef area in 1992 than was documented for the late 1960s l early 1970s (see Chapter Seven).

uisance Blooms and Red Tides

Nuisance blooms of various green algae and non-toxic **ioflagellates** occur occasionally, mainly in tributaries which e low circulation and high nutrient (e.g. nitrogen) sources. Such oms have been noted both in winter (for example in Clear Lake) l summer (for example Dickinson Bayou and Clear Lake) during m conditions when light penetration improves. These blooms be accompanied by oxygen depletion, particularly in enclosed situations, and can be triggered by summer low-flow conditions. Almost certainly, resulting oxygen depletion in the bay's bayous and stream tributaries is more widespread than currently acknowl-edged, due to a lack of oxygen measurements at night and during early morning hours when this depletion would be expected.

Toxic blooms (as determined by fish kills) are uncommon events within Galveston Bay. Fish kills and water discoloration caused by **red tide** blooms are periodically observed in the Gulf of Mexico but only occasionally noted inside Galveston Bay. For example, a major outbreak of the toxic red tide *Ptychodiscus brevis* occurred off much of the Texas coast 1986–1987 (detailed in Trebatoski, 1988). This incident resulted in one of the largest fish kills in recent times, but no evidence exists that this bloom entered any of Galveston Bay's inlets, as it entered several other Texas bays to the south.

Within the bay, most red tide blooms are caused by the dinoflagellate *Gonyaulax monilata*, and are of limited duration. This species produces a reddish-brown hue and toxins that can result in fish kills. One of the most notable red tides to affect the bay occurred in 1984 (Harper and Guillen, 1989).

ZOOPLANKTON

Zooplankton are microscopic drifting animals that feed on phytoplankton or smaller zooplankton. The status and trends of zooplankton in Galveston Bay are more difficult to determine than for phytoplankton, because of the lack of long-term studies and use of variable sampling techniques (primarily net size) by different researchers. The time of day that samples are collected is also important, as many estuarine zooplankton are diurnal vertical migrators (Minello and Matthews, 1981). Therefore, daytime zoo-plankton samples often underestimate total zooplankton population densities. The longest running data set extends from 1967 to 1980 for an area in Trinity Bay near the Cedar Bayou Generating Station (Buskey and Schmidt in Green et al., 1992).

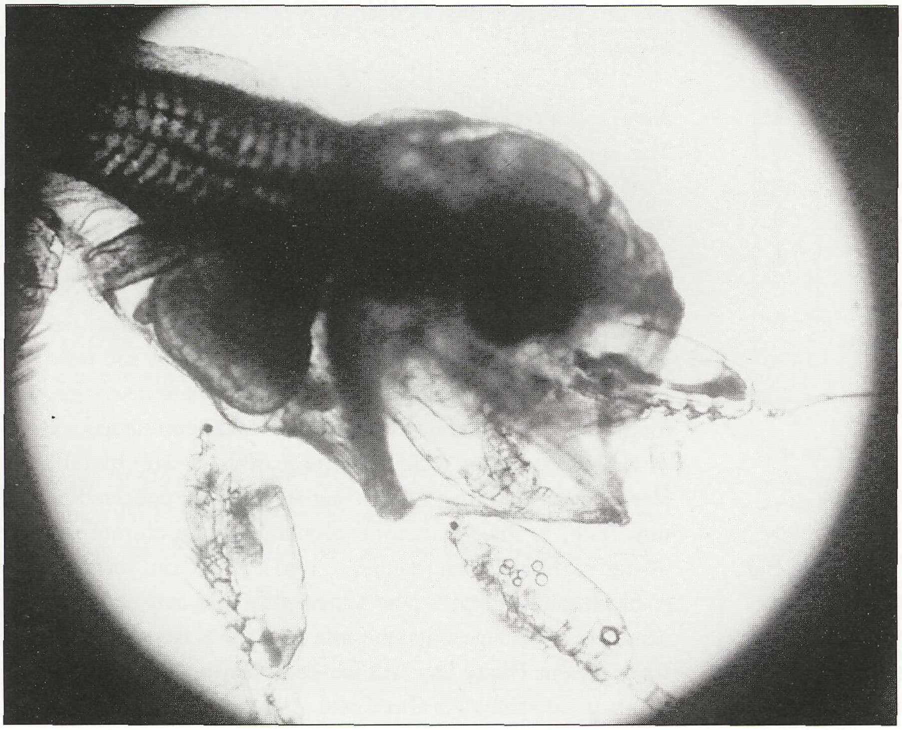
Like phytoplankton, zooplankton are often classified by size. Categories include **macrozooplankton** (visible range), **mesozoo-plankton**, **microzooplankton** (20-200 μm in size fraction), and **nanozooplankton** (2-20 μm). While some research has focused on the first two categories, few studies have focused on the smaller microzooplanton, even though they are probably responsible for grazing more phytoplankton biomass than the mesozooplankton (Buskey, 1989). The dominant zooplankton and mesozooplankton species in the Trinity Bay study include copepods, larval marine worms, and larval barnacles. *Acartia tonsa* (a copepod) is the domiant zooplankton species in Galveston Bay and other Texas estuaries (Lee et al., 1986).

Factors controlling zooplankton abundance are not well understood in Texas estuaries. However, some predictable changes can be correlated with changes in salinity. Large increases in zoo-plankton populations are often observed after extensive flushing of estuaries from high river runoff (Buskey, 1989). Other factors include food limitation during some parts of the year and effects of predators such as **ctenophores** (Day et al., 1987).

Data collected by the University of Texas Marine Science Institute reveal that Galveston Bay may have lower zooplankton abundance than many other Texas estuaries (Buskey and Schmidt in Green et al., 1992), with a typical range for Trinity Bay of 1,200 to 16,000 zooplankters per m^3 of water. The exact reasons for the high variability are unknown, although Buskey and Schmidt have speculated a link to industrial discharges. Based on several studies, they suggested that, in general, shallow, subtropical bays along the Texas coast may have lower zooplankton abundances than temperate estuaries.

BENTHIC ORGANISMS

Benthos refers to organisms that live in, on, or near the bottom, including plants, invertebrates, and fish of all sizes. Epifauna live on the surface of the bay bottom, while infauna burrow into the bottom, either superficially through fine sediments or deeper in vertical tubes. Many researchers focus on the benthic infauna, consisting largely of marine worms, brackish-water clams, other mollusks, and small crustaceans. Sampling of benthic invertebrates is performed by dredging or coring to collect sediment samples and then using sieves to separate organisms from the sediment. Because there is considerable variation in sampling techniques, it is difficult to compare absolute abundances reported in different studies.



Source: Texas Parks and Wildlife Department

A larval red drum feeds on zooplankton under the microscope. The plankton present in estuaries include algae, diatoms, larval fish and invertebrates, eggs of various species, and larger jellyfish and ctenophores.

Many benthic organisms are **filter feeders** that strain suspended organisms and organic matter from the water column, such as oysters feeding on phytoplankton. Deposit feeders, such as some worms, feed by ingesting sediments from the bay bottom and extracting nutrients. Still other benthic organisms graze on top of the sediments or are predators on other benthos.

Benthic organisms are an important component of the estuarine food web, fed upon by fish and birds, including Atlantic croaker, spot, mullet, drum, ducks, and other marsh birds. Recent research has determined that marsh benthos have a larger effect on estuarine fisheries than previously thought: juveniles of many fish species consume benthic organisms in tidally-flooded marshes (Zimmerman in Green et al., 1992). Overall, the benthic environment is heterotrophic–that is based on imported organic matter. Detritus that supports the benthic community originates from primary production in other parts of the estuary and its watershed.

Sediments are, of course, the matrix of the benthic environment. Within the sediment, a layering occurs, with oxidizing sediments on top, perhaps to a depth of several centimeters. Below this layer, and visible in benthic cores, is a darker-appearing reducing environment with little or no oxygen. This pattern influences many important benthic chemical process, shaping benthic ecology and benthic-pelagic chemical coupling–the chemistry of sediment/water equilibria. Particularly in shallow estuaries like Galveston Bay, this chemistry is important in both natural processes and in determining the fate, effects, and bio-availability of many pollutants. Sediments have an affinity for toxic pollutants and other materials that tend to accumulate on the bottom of the bay through sedimentation.

For several reasons, benthic organisms are good environmental indicators. Their relative immobility means they are continually exposed to any pollutants bound to sediments. Being on the bottom, they are first to experience the effect of oxygen depletion, since anoxia is generally most severe near the bottom (for example in the Houston Ship Channel). The high benthic community diversity under normal conditions tends to be replaced by a suite of fewer, more tolerant species in response to environmental stress, a pattern easy for a benthic ecologist to recognize.

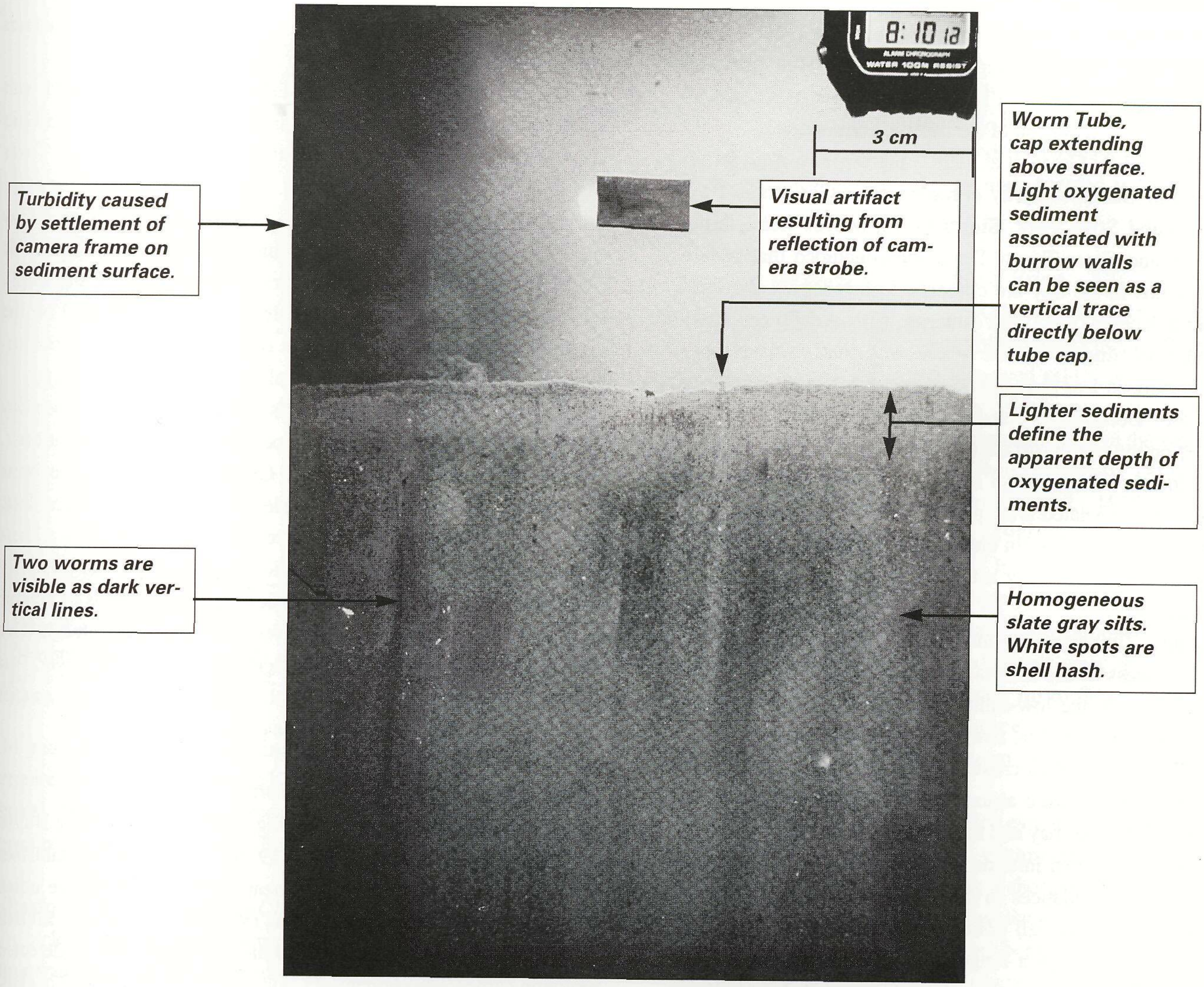
Below are discussions on the extensive open-bay benthic community, and the community in more limited marsh areas on the Bay's shorelines. The marsh benthic community may be an especially important component of the overall marsh habitat, serving as a food supply for numerous species. The estuary has been losing salt marsh habitat through conversion to open-bay habitat due, in large part, to localized shoreline subsidence and the associated incursion of the sea.

Open Bay Benthos

Parker (1960) defined several **macrobenthic** assemblages, primarily mollusks, and correlated them with salinity and substrate characteristics. Most of his work was performed from 1950 to 1957, a period of drought in Texas. During 1976 and 1977, White et al. (1985) collected single core samples on one-mile centers in Galveston Bay to define benthic assemblages and to measure the physical and chemical characteristics of the sediment. Typically, one or two species dominated a community composed primarily of polychaetes (marine worms), molluscs, and crustaceans. Muddy bottoms supported a richer polychaete community, while sandy bottoms supported more crustaceans. They reported that Galveston Bay exhibited low to moderate benthic diversity, with the highest diversity in areas with stable salinity regimes (e.g., near inlets such as Bolivar Roads and Rollover Pass). Galveston Bay and West Bay had twice the species richness of Trinity Bay or East Bay. Clear Lake, the San Jacinto River, and Houston Ship Channel had much lower species diversity than any of the open bay stations.

Recently, Ray et al. (1993) reported interim results from a four-year study of benthic assemblages in the lower and upper portions of the estuary that focused on potential impacts of dredged materials. Ray et al. concluded that observed patterns in benthic assemblages were primarily attributable to the prevailing salinity regime, and secondarily influenced by substrate type (for example shell hash compared to mud). In general, the benthic infauna were described as "opportunistic species adapted to a dynamic salinity regime and variable physical conditions typical of shallow Gulf of Mexico estuaries."

Spatially, open-bay benthos generally increase in abundance



Source: U.S. Army Corps of Engineers

For this photograph, a special apparatus was inserted into the bottom of Galveston Bay, revealing a cross section of sediment to a depth of several inches. Several features of typical soft sediment habitat are revealed. The light-colored layer on the sediment surface corresponds to oxygenated sediments, here less than one centimeter deep. To the right of center at the sediment-water interface is a worm tube cap extending above the surface, and causing the light oxygenated sediments to penetrate downward along the tube. Beneath the oxygenated sediments are fine-grained silts, punctuated by lighter bits of shell. (The dark rectangle top center is a camera strobe reflection).

from the Trinity Bay-Upper Bay region to the Lower Galveston-West Bay region (Harper in Green et al., 1992). This is opposite of the trend observed in San Antonio Bay, which is south of and has higher salinity than Galveston Bay (Matthews and Marcin, 1973; Harper, 1973, Harper and Hopkins, 1976).

Temporally, a seasonal trend is observed, with peak abundances in spring, between February and May, and decline in October and November (Harper in Green et al., 1992). As open-bay benthos are very good indicators of salinity, fresh water flood events can alter this cycle.

Marsh Benthos

Marsh areas are vital ecological components in **nutrient cycling**, **carbon flux**, and sediment binding, and are habitat for many types of plants and animals (see Chapters Three and Seven). In Galveston Bay, brown shrimp, white shrimp, blue crab, red drum, spotted seatrout, southern flounder, and Gulf menhaden all depend upon the marsh portion of the benthic community.

Zimmerman (in Green et al., 1992) performed a study of six marshes in the Galveston Bay complex near Christmas Bay, Galveston Island State Park, Smith Point, Moses Lake, Inner Trinity Delta, and Outer Trinity Delta. He concluded that marsh-dwelling benthos in the bay are comprised of generally the same species found in other Gulf Coast estuaries, with over 90 percent of the infauna consisting of marine worms and small crustaceans). Mollusks comprised less than three percent of infaunal abundance at any one site. Densities of marsh infauna and epifauna were generally higher on the marsh surface than in bare subtidal habitat adjacent to the marsh. In the marsh itself, infauna were usually more numerous when associated with plants, than in the bare substrate between plants (Zimmerman in Green et al., 1992). The local benthic assemblage was strongly affected by salinity, a significant influence bay-wide.

Spatially, Zimmerman found the highest densities and greatest species richness in the mid-salinity marshes near Moses Lake and Smith Point. In the low-salinity marshes associated with the upper bay/Trinity River delta, marine worms dominated the infaunal community, while small crustaceans were absent. In the high salinity lower bay, benthic abundance and richness values fell between the other upper-bay and mid-bay systems.

Temporally, marsh infauna displays a seasonal periodicity, with peak yearly abundances in late winter and early spring and lower abundances in the fall (Zimmerman in Green et al., 1992; based on annual data from a long-term study of marshes near the Galveston Island State Park). The abundance of benthic predators is the primary cause for this seasonal pattern; shrimp, crab, and fish predators are more abundant in warm weather.

Zimmerman et al. (1991) indicated that marshes which are drowning (as a result of subsidence and the associated relative rise in sea level) have higher secondary productivity than stable marshes, until they are succeeded by open-bay habitat. This creates a temporarily beneficial situation for fish, invertebrates, birds, reptiles, and mammals that use the marsh, due to increase in: 1) estuarine area; 2) the duration of access due to flooding; and 3) the interface between the marsh and open bay. Therefore, secondary productivity increases for a short period, until the drowning marsh is converted to open-bay habitat, at which point the secondary productivity and habitat diversity decline.

Man-Made Perturbations to Benthos

Urban and Industrial Runoff

Carr (1993) conducted a sediment quality triad study of Galveston Bay for the Galveston Bay National Estuary Program, in which a series of sediment samples were analyzed for three parameters: 1) contaminants; 2) toxicity; and 3) benthic abundance and diversity. This study is reported primarily in Chapter Six (see FIGURE 6.16). For benthos, the "significantly altered level" was defined as samples with fewer than ten species and total abundance less than 100 organisms.

Carr's study analyzed six stations directly associated with urban and/or industrial runoff: Burnett Bay in the Houston Ship Channel; Kemah Flats near the outfall of Clear Lake; near Texas City; Black Duck Bay near local industrial treatment lagoons; Swan Lake; and Dollar Bay. Two of these stations, Burnett Bay and Black Duck Bay, had significantly altered levels of benthic organisms from "contaminant-induced degradation" (Carr, 1993). Both of these small, partially-enclosed bays are located on the upper Houston Ship Channel. The other four urban/industrial stations did not exhibit a significantly altered benthic community.

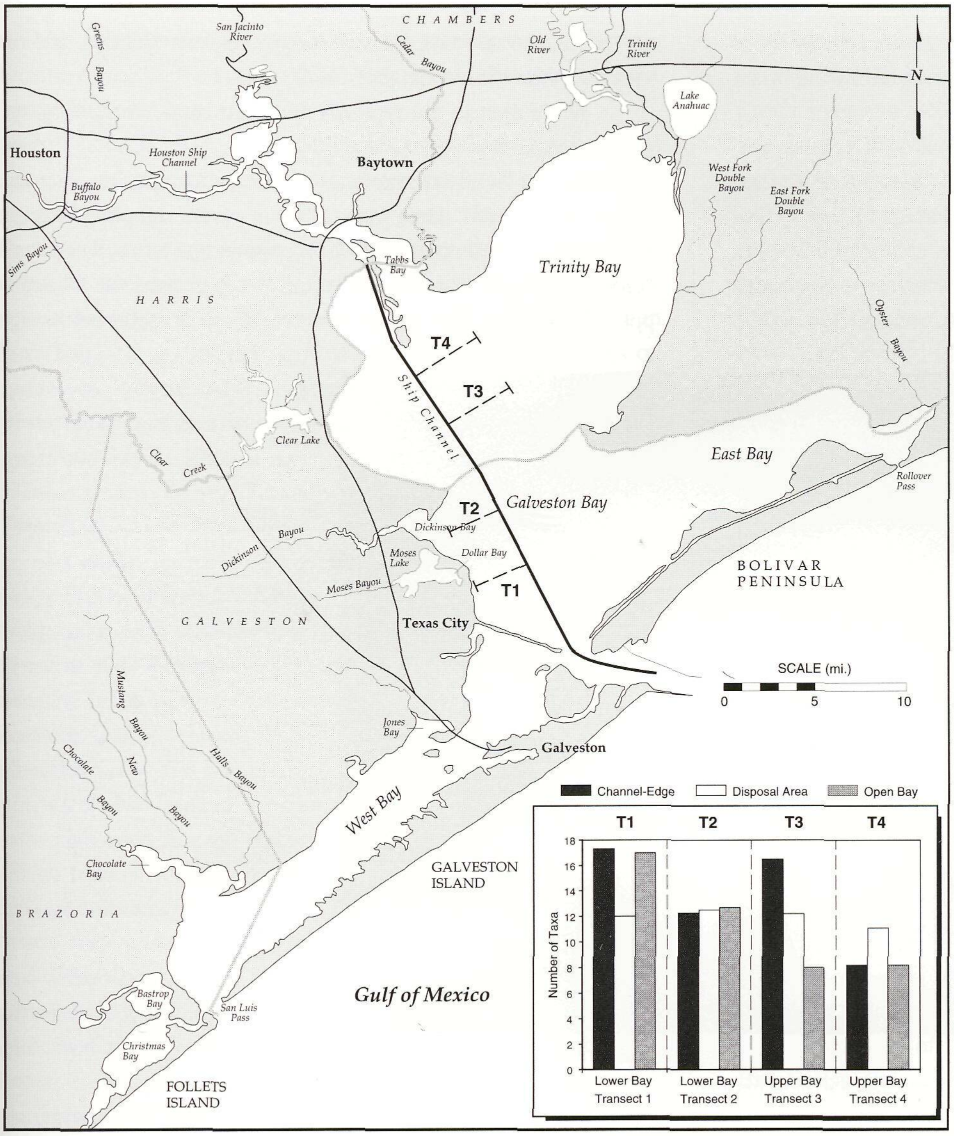
For comparison, 13 of Carr's stations, located in open bay waters away from local runoff and petroleum production platforms, showed fewer community impacts. Of these 13 stations, three were selected because they had known elevations of either copper, lead, strontium, or chromium; the study revealed toxicity effects at these stations. Of the remaining ten stations representative of open bay conditions, only one showed "significantly altered levels of benthic organisms" as defined in the study. This station, located in East Bay, did not have contaminant-induced degradation; however, East Bay was determined by White et al. (1985) to have lower species richness than most other parts of the open bay.

Cedar Bayou Generating Station

As part of Houston Lighting and Power's Cedar Bayou Generating Station project in the 1970s, investigators established several benthic sampling stations near intake and discharge points as well as several reference stations (Williams, 1972; and McBee, 1975). No effect from the power plant's effluent could be detected, although some improvement in Cedar Bayou was observed because upstream brine discharges were diluted by bay water drawn upstream to the power plant intake (Harper in Green et al., 1992).

Oyster Shell Dredging

Although oyster shell dredging has not been conducted in Galveston Bay for over 20 years, data from San Antonio Bay suggest that this practice had long-term effects. In San Antonio Bay, some holes caused by oyster shell dredging were still visible after



Source: Ray et al., 1993

FIGURE 8.5. Benthic infauna (sediment-dwelling organisms) are an important indicator community in Galveston Bay. Benthic diversity along four transects extending from the Houston Ship Channel to the open bay is indicated here. In general, the more stable salinities of the lower bay system support slightly higher benthic community diversity.

24 years (Harper and Hopkins, 1976). About five years were required to obtain near-normal levels of macrobenthos in dredged holes. No direct research assessing impacts of shell dredging has been performed in Galveston Bay.

Dredging for Navigation Channels

Ray et al. (1993) documented benthic assemblages along four transects running perpendicular to the Houston Ship Channel as part of a four-year Corps of Engineers study. They used a specialized camera system to obtain images of the vertical sediment cross-section at the sediment-water interface (see photo page 163), along with conventional box coring methods to analyze benthic communities. Their preliminary findings indicate that dramatic differences in benthic community structure do not occur between the channel-edge, dredged material disposal area, and undisturbed open-bay habitats (FIGURE 8.5).

A companion study by Clarke et al. (1993) was performed to measure the rate of recovery of benthic populations after placement of a stiff Pleistocene clay on open-bay bottoms to simulate dredged material disposal in Galveston Bay. Two 23-ac experimental plots, one in the upper bay and one in the lower bay, were constructed along with four undisturbed reference plots. Preliminary data during the first 15-21 weeks of the test revealed some weathering of hard clay sediments. Recruitment of benthic taxa to the disturbed bay bottoms occurred rapidly, although in a patchy fashion. Overall benthic assemblage densities remained depressed after the initial 15-21 week period, but signs of recovery were observed for biomass and taxa in one of the mounds located in lower Galveston Bay.

Oil Field Brine

Releases of oil field produced water (highly concentrated brines containing dissolved oil-related constituents; see Chapter Six) have significant impacts on benthic assemblages in the vicinity of produced water outfalls (Mackin, 1971; Armstrong et al., 1979; Nance, 1984; Harper, 1986; and Roach et al., 1993a, 1993b). In most of these studies, the area immediately around the outfall was found to contain hydrocarbons in the sediments, and sediments were devoid of benthic organisms up to 50 meters away. The abundance of benthic organisms increased with distance away from the discharge to a maximum located 500–1500 meters away.

Roach et al. (1993a, 1993b) evaluated impacts of produced water discharges on benthic organisms at two locations in Galveston Bay, one representing a shoreline/open bay habitat and one a tributary habitat. Sampling stations nearest to the tributary outfall exhibited an absence of any benthic organisms, while greatly depressed populations were observed adjacent to the shoreline discharge. In both cases the outfall was determined to have contaminated the adjacent sediments to the extent that benthic infauna were absent or only minimally colonizing the sediments.

OYSTERS

Two oyster species inhabit Texas Coastal waters: the Gulf oyster (*Ostrea equestris*), which prefers higher salinity waters associated with open bays, Gulf passes, and the Gulf; and the

Eastern oyster (*Crassostrea virginica*), which grows abundantly in the brackish waters of enclosed bays and is commercially important (Quast et al., 1988).

The life cycle of the Eastern oyster begins with a free-swimming larval stage that eventually attaches to a hard substrate (frequently existing reef shell), forming an oyster spat. The spat commences a growth period that is classified into sub-adult and adult phases. Oysters generally spawn when the water temperature reaches and stays at or above 20° C; in the Galveston Bay system this usually occurs in June or July after the ambient temperature has increased to 25° C. Oyster larvae, spat, sub-adults and adults are all filter feeders on phytoplankton.

Source: Texas Sea Grant College Program

Typical oyster reef, seen through non-typically clear water over a shallow bay reef.

Physical Factors

Oysters are most successful in habitats that provide a firm substrate for attachment, good water circulation, and suitable water temperature and salinity. The most suitable substrate is generally the shell (of both living and dead oysters) associated with existing reefs. Several layers of live oysters result, with the youngest on the top. These natural reefs are primarily of four types: 1) alongshore reefs oriented parallel to shore and located near or attached to the shoreline; 2) reefs extending perpendicular from the shoreline or a point nearshore out into the bay; 3) patch reefs composed of one or more relatively small more-or-less circular bodies; and 4) barrier reefs extending across or nearly across the bay.

Specific water flow requirements for Texas oysters are not known (Quast et al., 1988). Galtsoff (1964) determined that for maximum feeding, current velocities fast enough to exchange water above a reef three times an hour are required. Oysters can tolerate water temperatures as low as one °C and as high as 36°C, however, optimum water temperatures for growth, reproduction, and survival of Texas oysters ranges from 20 to 30°C.

While oysters are typically found in areas where long-term salinity ranges between ten and 30 ppt, salinity effects on the population depend largely on the range of fluctuation and rate of change (Quast et al., 1988). Data from 23 years of reef sampling indicated the best spat sets (corresponding, in commercial terms, to an oyster "crop") occurred when spring salinity ranged between 17 and 24 ppt. The poorest sets occurred when salinity dropped below eight ppt (Hofstetter, 1983). Oysters in Trinity Bay have survived salinity less than five ppt for two to three weeks but experienced over 90 percent mortality when exposed to near-fresh water with less than two ppt salinity for three weeks (Quast et al., 1988). A short term lowering of salinity (five to ten ppt for two to six weeks) is beneficial to oysters because it reduces predation by oyster drills and stone crabs. Such salinity reductions also reduce the infection rate and effects of **dermo**, caused by *Perkinus marinus* (see below).

Before reservoirs were constructed on the rivers that emptied into Texas bays, large floods reached and passed through the bays relatively quickly (Hofstetter, 1977). While salinity was reduced to the point where oysters were sometimes killed, the duration of the "freshet" was relatively short, and oyster populations reestablished themselves relatively quickly. With the reservoirs in place, the salinity is still reduced, but the duration of the freshet is extended. Longer freshets are more destructive than rapidly passing floods, thereby potentially increasing the stress on oyster populations (Hofstetter, 1977).

Biological Factors

Oysters are stressed by competition, parasites, diseases, and predation from other organisms. The most important of these biological stresses in Galveston Bay is infection by "dermo," *Perkinsus marinsus* (Powell et al., 1994), a protozoan parasite that ranges from Delaware to Mexico. Mortality of market oysters in Galveston Bay resulting from this parasite can range from ten percent to 50 percent annually, and the mortality rate increases with increasing temperature. In a May, 1992 survey of Galveston Bay oyster populations, Powell et al. (1994) found that the highest prevalence of *Perkinsus marinsus* was found in West Bay, where over 50 percent of the oysters were infected. The authors noted that this infection rate was lower than the rates reported by others because of the unusually low salinity conditions that occurred during the four months prior to sampling.

Oysters compete with other benthic organisms for space and nutrients and are food sources for several predators. Competitors include barnacles, mussels, worms, and algae (Quast et al., 1988). Predators that feed on oysters include stone crabs, mud crabs, blue crabs, the southern oyster drill, and some finfish. In the oyster survey conducted in 1992, the southern oyster drill was only found in West Bay and on Half Moon Reef. Highest crab abundances on oyster reefs (mostly mud crabs) were found in West Bay, the southwestern portion of Redfish Bar to Smith Point, and in the Red Bluff area (Powell et al., 1994).

Trends in Space and Time

A review of old maps of the Texas coast archived in the General Land Office indicated an extensive loss of shoreline (intertidal) oyster reefs in Galveston Bay. However, recent research by Powell et al. (1994) indicated an increase in overall oyster reef area since the 1970s. Chapter Seven includes a discussion of the change in oyster reef habitat since the 1970s and shows the current location of reefs in Galveston Bay.

The abundance of spat, small and market oysters decreased in the Galveston Bay system between 1956 and 1977 (Quast et al., 1988). After a sharp increase in abundance between 1980 and 1982, abundance continued to decline through 1987. For example, oysters were measured using a 35-liter oyster dredge at three sites on Redfish Bar between 1956 and 1984 (Hofstetter, 1977). The annual mean number of oyster spat was 113 between 1956-1966, 34 between 1967 and 1977, and 44 between 1978 and 1984. Between 1956 and 1982, the annual mean number of market oysters (greater than 76 mm) in Galveston Bay samples generally fluctuated between 20 and 40 individuals (Hofstetter, 1977). Responding to high fresh water inflow, 1982 samples peaked at 68 individuals per sample, and then declined to pre-1982 levels again in 1984.

Landings of Galveston Bay oysters have fluctuated through the years, with a marked increase after 1960 (see Chapter Four). Fishing pressure has increased significantly, however, and Quast et al. (1988) concluded that the oyster was overfished in Texas (although recent research indicates that the oyster harvest has not harmed the oyster reef habitat–see Chapter Seven). From 1982-1986 about 81 percent of the Galveston Bay oyster harvest came from public reefs, with the remainder from private oyster leases issued by the state.

Vitality of Reefs

The results of a reef survey, a health survey, and computer modeling simulations suggest that the most productive region of Galveston Bay for oysters is the area associated with the salinity gradient produced by the Houston Ship Channel (Powell et al., 1994). Areas along the channel produced the healthiest oyster populations, as measured by density, size-frequency distribution, and reproductive state. In addition, the study indicated the South Redfish Reef and Houston Ship Channel could be important natural brood areas, producing larvae for the bay as a whole. Current flow and food availability appear to be the key determinants of local variations in population health.

Reefs near Pelican Island and central West Bay are supporting much lower production than would be expected from known conditions and historical indicators (Galtsoff, 1931). The Texas City Dike is probably responsible for at least of a portion of the low oyster productivity in these areas because it restricts circulation in West Bay (Powell et al., 1994).

Additional research performed by Powell et al. (1994) addressed the relationship between food supply and oyster populations in Galveston Bay. They suggested that large oysters (greater than 90 cm) are relatively rare in Galveston Bay, and that overall, Galveston Bay now has a planktonic food supply just barely adequate to support a market-size population. Since phytoplankton, the primary food supply for oysters, has shown declining populations since the 1970s, there is speculation that the amount of future oyster harvests may be affected.

FINFISH, SHRIMP, AND CRAB POPULATIONS

The Galveston Bay system maintains important recreational and commercial fisheries for shrimps, crabs, and fishes. During the last 100 years, the total landings from the estuary have doubled, mostly due to shrimp and crabs (total landings of other species have remained essentially unchanged, excepting decreases for striped bass and grouper). How have the various bay species fared under this increased fishing intensity?

Two types of information are available regarding Galveston Bay finfish and shellfish populations: 1) commercial and recreational landings of shrimps, crabs, oysters, and finfish (presented in Chapter Four); and 2) scientific measurements of indicator species conducted by marine fisheries organizations. Note that the first type of data is fishery-dependent (the results are based upon both the intensity of fishing effort and the abundance of the organisms), while the data of the second type are fishery-independent (scientific capture studies based only on the abundance of organisms) and provide better information to estimate actual population sizes. Fishery independent scientific studies (Green et al., 1992; Green et al., 1993) are the focus of this section.

Scientific trawling studies by the Texas Parks and Wildlife Department have identified about thirteen species of shrimp, seventeen species of crab, and over 150 finfish species in the bay (McEachron et al., 1977; Parker, 1965; Loeffler in Green et al., 1992). In one two-year trawl study for fish, six species were found to account for 91 percent of the total number of fish collected: Atlantic croaker (51 percent); bay anchovy (22 percent); star drum (8 percent); spot (4 percent); sand seatrout (3 percent); and sea catfish (3 percent). These six species, plus striped mullet, accounted for 74 percent of the fish biomass collected, whereas Atlantic croaker alone represented 34 percent of the total fish biomass (Sheridan et al., 1989). TABLE 8.3 lists the common and scientific

TABLE 8.3. List of Common and Scientific Names of Commercial and Recreational Finfish and Shellfish Species Caught or Landed in Texas.

Common Name	Scientific Name	Common Name	Scientific Name
Finfish		Pinfish	*Lagodon rhomboides*
Alligator gar	*Lepisosteus spatula*	Red drum	*Sciaenops ocellatus*
Atlantic croaker	*Micropogonias undulatus*	Seatrout	
Atlantic cutlassfish	*Trichiurus lepturus*	Sand seatrout	*Cynoscion arenarius*
Atlantic moonfish	*Selene setapinnis*	Silver seatrout	*Cynoscion nothus*
Atlantic needlefish	*Strongylura marina*	Spotted seatrout	*Cynoscion nebulosus*
Atlantic spadefish	*Chaetodipterus faber*	Shark	
Atlantic stingray	*Dasyatis sabina*	Atlantic sharpnose	*Rhizoprionodon terraenovae*
Black drum	*Pogonias cromis*	Blacktip	*Carcharhinus limbatus*
Bluefish	*Pomatomus saltatrix*	Bull	*Carcharhinus leucas*
Blue catfish	*Ictalurus furcatus*	Scalloped hammerhead	*Sphyrna lewini*
Channel catfish	*Ictalurus punctatus*	Smooth dogfish	*Mustelis canis*
Cobia	*Rachycentron canadum*	Sheepshead	*Archosargus probatocephalus*
Flounder		Silver perch	*Bairdiella chrysoura*
Gulf flounder	*Paralichthys albigutta*	Lane snapper	*Lutjanus synagris*
Southern flounder	*Paralichthys lethostigma*	Southern stingray	*Dasyatis americanus*
Florida pompano	*Trachinotus carolinus*	Spot	*Leiostomus xanthurus*
Freshwater drum	*Aplodinotus gruniens*	Striped burrfish	*Chilomycterus schoepfi*
Gafftopsail catfish	*Bagre marinus*	Tripletail	*Lobotes surinamensis*
Gulf butterfish	*Peprilus burti*		
Hardhead catfish	*Arius felis*	**Shellfish**	
Kingfish		Crab	
Gulf kingfish	*Menticirrhus littoralis*	Blue crab	*Callinectes sapidus*
Southern kingfish	*Menticirrhus americanus*	Stone crab	*Menippe mercenaria*
Ladyfish	*Elops saurus*	Eastern oyster	*Crassostrea virginica*
Mackerel		Shrimp	
King mackerel	*Scomberomorus cavalla*	Brown	*Penaeus aztecus*
Spanish mackerel	*Scomberomorus maculatus*	White	*Penaeus setiferus*
Menhaden	*Brevoortia patronus*	Pink	*Penaeus duorarum*
Mullet		Rock	*Sicyonia brevirostris*
Striped mullet	*Mugil cephalus*	Seabob	*Xiphopenaeus kroyeri*
White mullet	*Mugil curema*	Squid	
Ocellated flounder	*Ancylopsetta quadrocellata*	Brief squid	*Lolliguncula brevis*
Permit	*Trachinotus falcatus*	Long-finned squid	*Loligo pealei*
Pigfish	*Orthopristis chrysoptera*		

Source: Sheridan et al., 1989

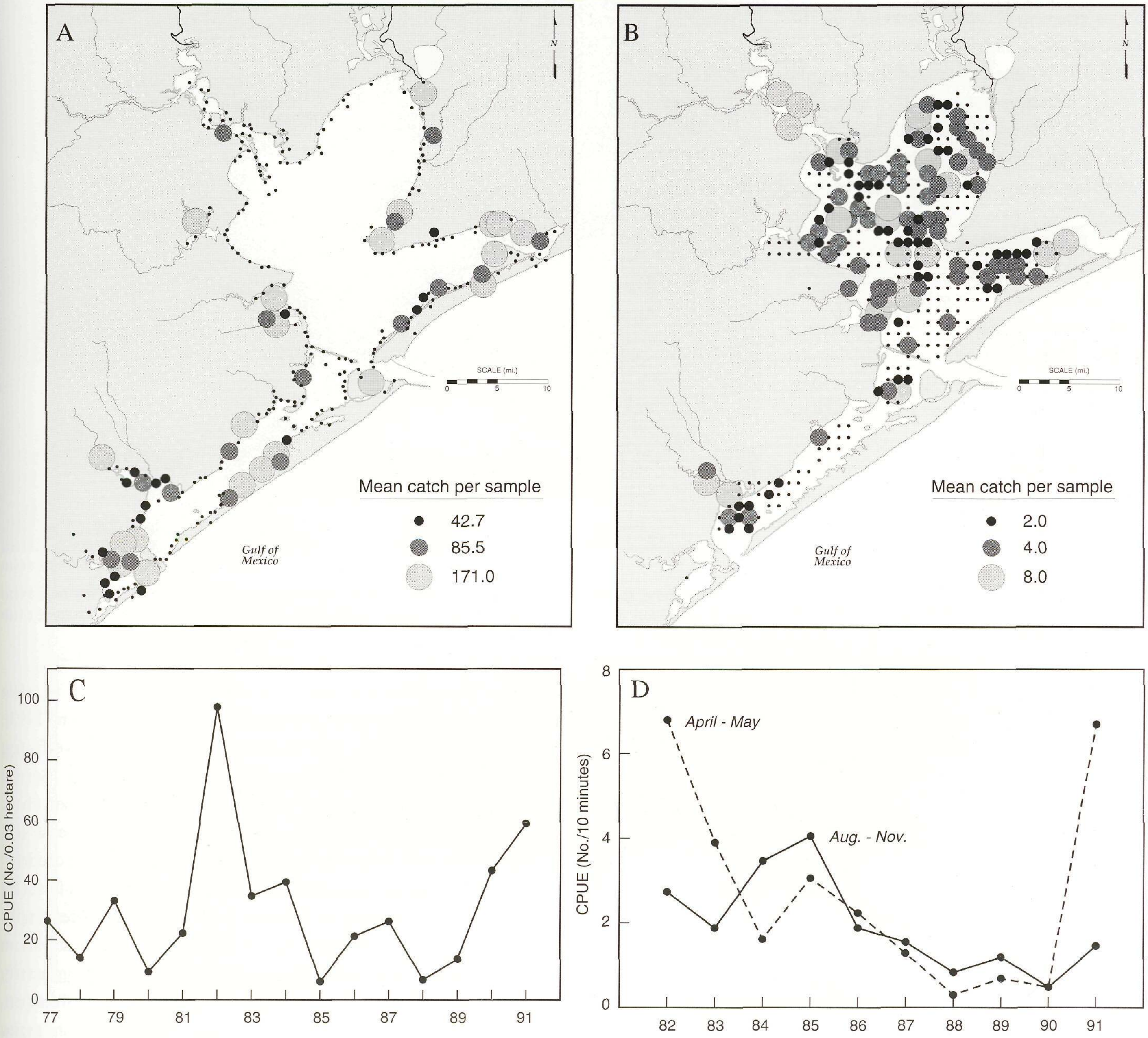
names of commercial and recreational finfish and shellfish reportedly caught or landed in Texas.

The Texas Parks and Wildlife Department sampling data indicated that the "overall health of the Galveston Estuary appears to be fair to good" (Green et al., 1992). There were significant increases in some finfish populations, including red drum, spotted seatrout, and Atlantic croaker. Certain species have shown some evidence of potential decline, such as white shrimp (although recent data indicates a rebound) and large size classes of the blue crab.

Methodology and Data

The Texas Parks and Wildlife Department utilizes several techniques, including: 1) seines for collecting smaller organisms in near-shore environments; 2) trawls for collecting organisms found on or near the open bay bottoms; 3) gill nets for catching larger fish near shore; and 4) oyster dredges for sampling macro-benthic shellfish and encrusting organisms. Raw data are compiled to estimate the mean catch per sample for comparing spatial trends, and the **catch per unit effort** (CPUE) for temporal trends. CPUE is defined as the number of individual fish/shellfish caught for a given area seined or time trawled.

Throughout the following section, spatial distributions of finfish and shellfish are illustrated in "bubble charts," in which the size of each bubble is proportional to organism numbers (CPUE, mean



Source: Green et al., 1992

FIGURE 8.6. White Shrimp abundance distributions and temporal trends. Young-of-the-year are shown in (a), caught with bag seines along the shoreline (35-55 mm size, June-November, 1977-1989), while (c) reveals the corresponding abundance trend over time. First-time spawners are shown in (b), caught with trawls in open bay waters (110-130 mm size, August-November, 1982-1990), and (d) presents the corresponding time trend. The decline in spawners has prompted management concerns for this species (see text).

catch per sample), with locations determined by latitude-longitude coordinates taken during sampling. Each map represents a particular species age class, with shoreline bubbles corresponding to bag seines and open-water bubbles relating to otter trawl samples.

Temporal trends are defined using graphs of CPUE vs. year. Most graphs represent a ten to 15-year time span for a specific size class of a particular species. In addition to the data, a statistical trend line and associated 95 percent confidence interval is presented for some species (see FIGURES 8.10–8.11). Typical size classes from youngest to oldest are: 1) young-of-the-year; 2) juveniles; 3) first time spawners; and 4) adults.

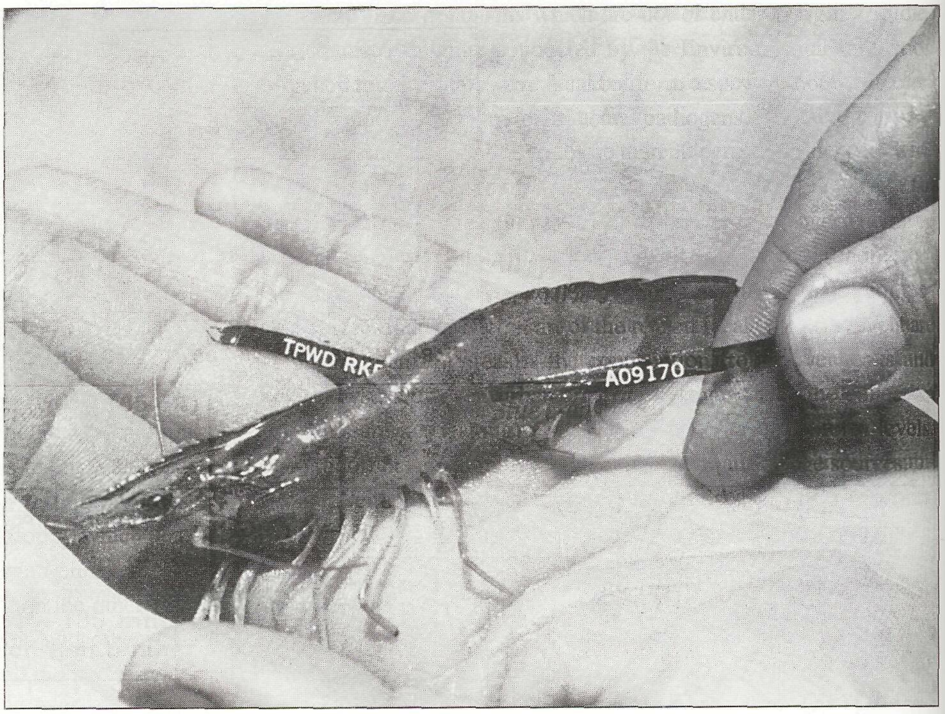
Selected Species Summaries

The spatial distribution and temporal trends for several selected species are presented in this section. White shrimp and blue crab were selected because of their observed decline in relative abundance. Two finfish were selected for detailed graphical presentation. The spotted sea trout is a recreational species and top carnivore, and the bay anchovy is an important element of the lower food web in the open bay. More detailed information (maps, CPUE graphs, and other data) on these four species and ten additional species are presented in Green et al. (1992).

White Shrimp

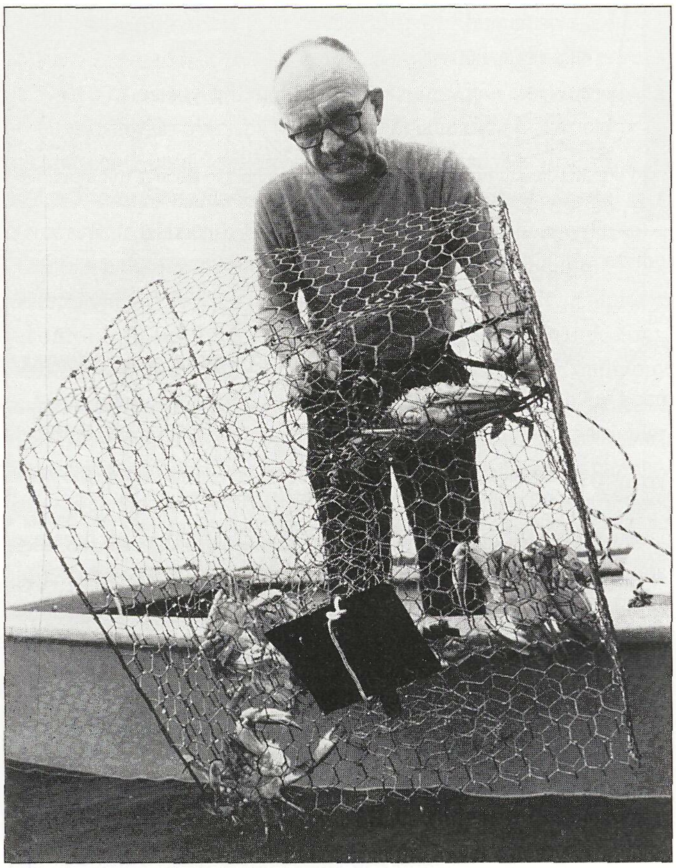
The near-shore and open-bay distribution of white shrimp is depicted in FIGURE 8.6. Young-of-the-year white shrimp emerge from marsh areas in East Bay, West Bay and Christmas Bay during June-December. In the open bay, first-time spawning shrimp cluster in the mid to upper bay.

A strong decline in white shrimp was observed from 1982 through 1990, leading to concern about the condition of the bay's white shrimp population (Walton and Green, 1993; Green et al., 1993). Similar declines were noted in the Aransas Bay, Corpus Christi Bay, and Laguna Madre estuaries. However, recent sampling results from 1991 show a large rebound to 1983 population levels (Walton and Green, 1993). The rebound is probably at least partially the result of increased fresh water inflow due to extremely wet conditions in 1990 and 1991, and management actions discussed below.



Source: Texas Parks and Wildlife Department

Shrimp tagging studies by the Texas Parks and Wildlife Department help managers to assess population stocks, migration, and survivorship. This information can then be used to determine biologically appropriate harvest regulations.



Source: Texas Parks and Wildlife Department

The blue crab fishery in Galveston Bay has expanded in recent years, resulting in declines in adult size classes, particularly due to capture of adult males in the upper, river-influenced portion of the estuary.

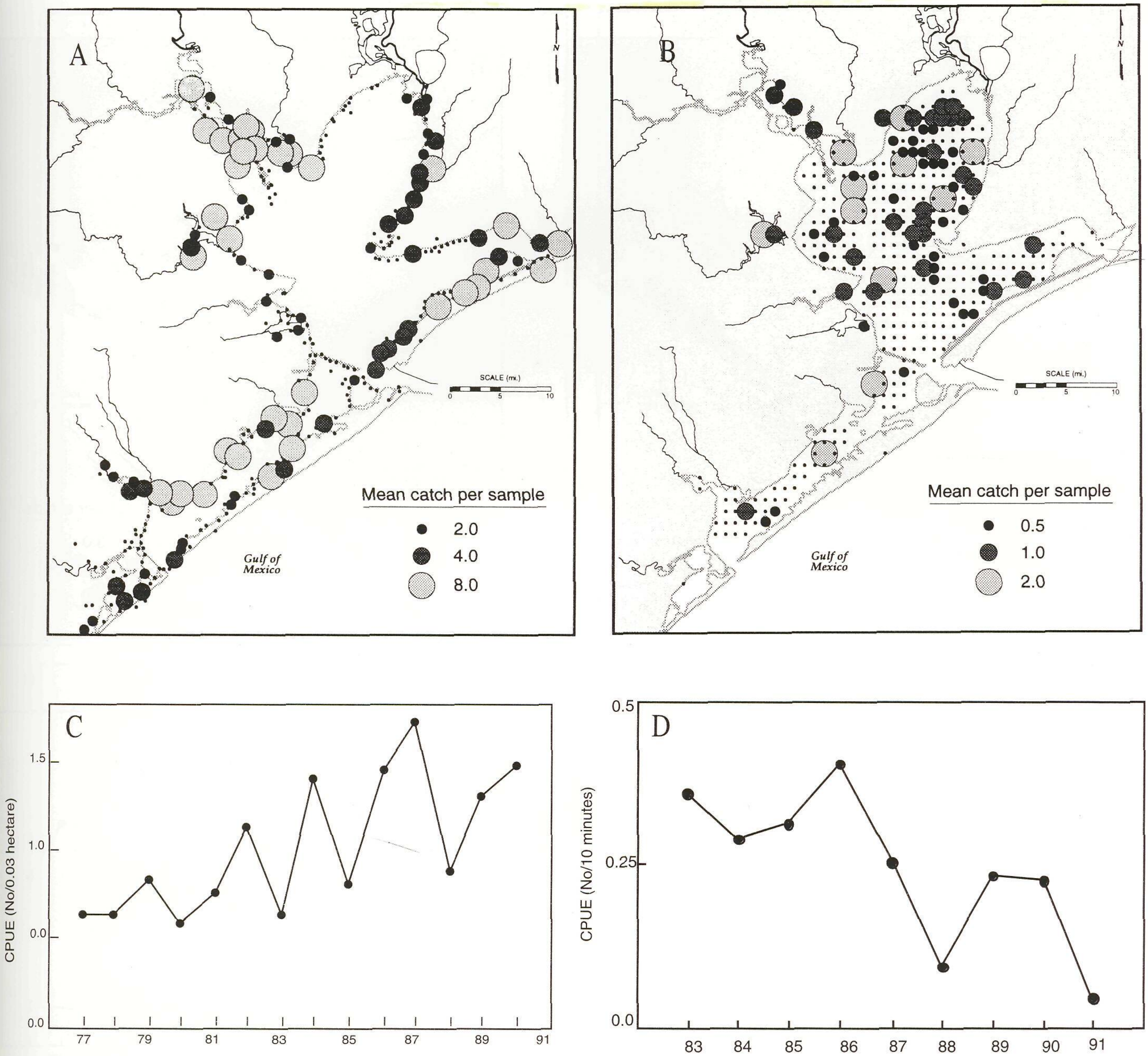
Three potential causes for the observed decline in white shrimp, 1982–1992 were discussed by Walton and Green (1993): overfishing, pollution, and low fresh water inflows. Overfishing was deemed the most obvious possibility for the decline. Several other factors such as loss of wetlands, a change in the food chain, and increased predation were considered but ruled out because similar species such as brown shrimp did not exhibit a similar decline.

Based on the supposition that over-harvest can be a factor for white shrimp, changes in fisheries regulations have been implemented by the Texas Parks and Wildlife Department at various times to protect the white shrimp resource. Shrimping in nursery areas was prohibited in 1979, except for "grandfathered" shrimpers, who continued to shrimp these areas until 1989. Night shrimping was banned during spring months in 1990. Most importantly, starting in 1990, all shrimping was banned for two summer months in the Gulf of Mexico, a major white shrimp spawning area.

Blue Crab

More blue crabs are landed in Galveston Bay than in any other Texas estuary (Walton and Green, 1993). Blue crab landings have increased from about 200,000 pounds per year in 1960 to over three million pounds per year in 1990 (see Chapter Four). This trend is partly because of the increasing value of blue crabs.

The population analysis indicated a more complex seasonal trend for this species than for many estuarine organisms. Small near-shore juveniles (less than 25 mm in width) peaked in March, while larger near-shore blue crab populations peaked in the summer. Smaller open-bay crabs indicated a peak abundance in April.



Source: Green et al., 1992

FIGURE 8.7. Blue crab abundance distributions and temporal trends. Young-of-the-year are shown in (a), caught with bag seines along the shoreline (25-45 mm size, January-December, 1978-1989), while (c) reveals the corresponding abundance trend over time. First-time spawners are shown in (b), caught with trawls in open bay waters (120-140 mm size, January-December, 1983-1990), and (d) presents the corresponding time trend. The decline in spawners was related to overharvest, particularly of males in the upper estuary.

and larger sizes (greater than 120 mm) peaked in June. Higher near-shore abundance for young-of-the-year blue crabs was noted in the area above Morgans Point, the eastern fringe of Trinity Bay, north of Bolivar Peninsula, and around fringes of West Bay. For open-bay trawls, more young-of-the-year blue crabs were found in Trinity Bay (FIGURE 8.7).

Blue crabs had different temporal trends for different size classes: smaller crabs increased in abundance from 1983 to 1990 while the larger sizes decreased. For example, the mean size of crabs collected in trawl samples dropped from 91 mm in 1982 to 71 mm in 1988 (Mambretti et al., 1990). Recruitment did not appear to be a problem, as smallest crab sizes increased in number (Green et al., 1992). Because blue crabs are mobile and widely dispersed off the entire Texas coast, strong recruitment might continue even if the in-bay adult population were reduced (Walton and Green, 1993).

These results indicated a blue crab decline in the lower salinity upper-bay zone, directly implicating overfishing of male blue crabs (Walton and Green, 1993). Females need to migrate to higher salinity water to spawn, while males do not. Therefore, males spend more time in fresher parts of the bay and consequently are targeted by fishermen in the upper estuary. In addition, male

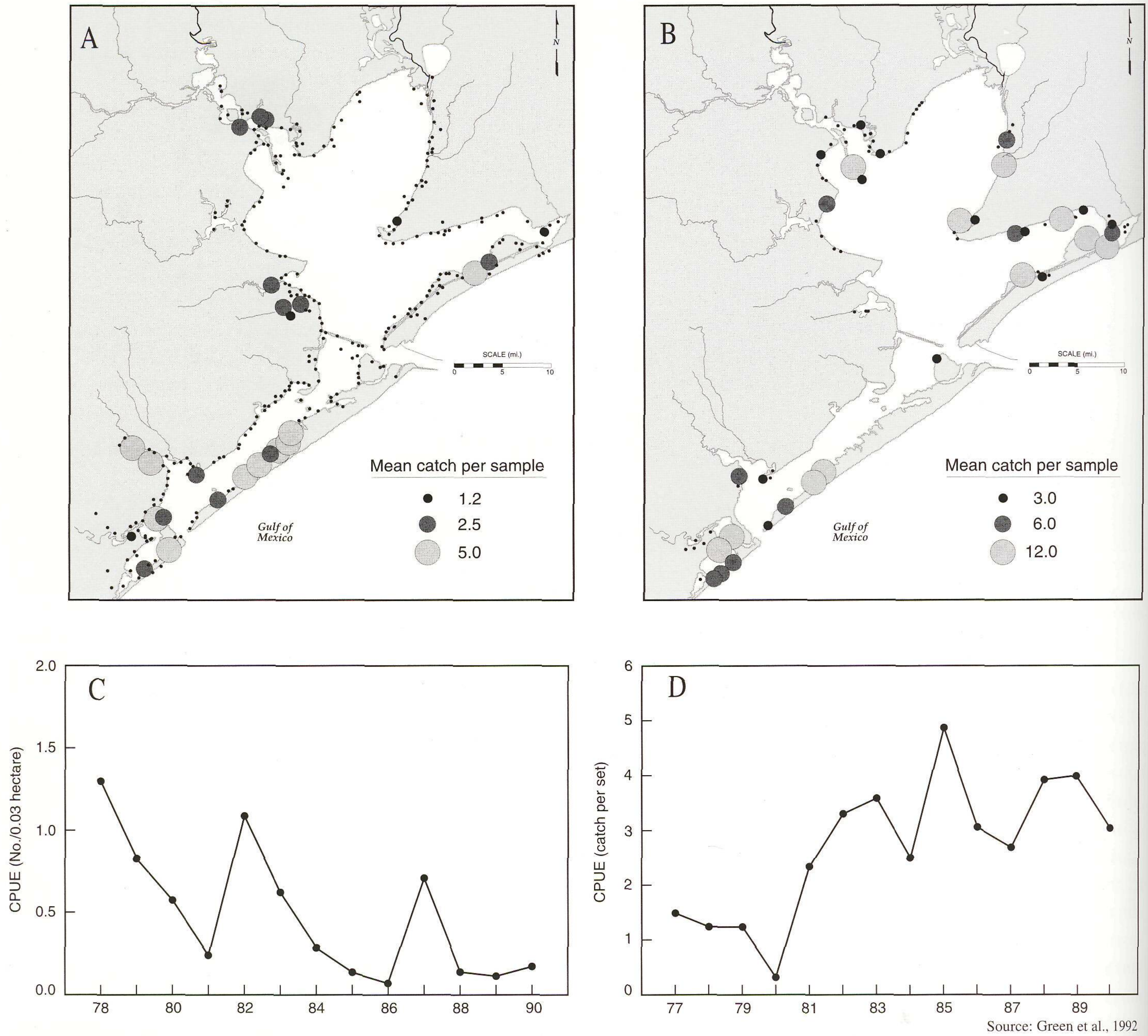


FIGURE 8.8. Spotted seatrout abundance distributions and temporal trends. Young-of-the-year are shown in (a), caught with bag seines along the shoreline (35-75 mm size, July-December, 1978-1989), while (c) reveals the corresponding abundance trend over time. First-time spawners are shown in (b), caught with gill nets (> 450 mm size, Spring 1977-1990), and (d) presents the corresponding time trend. The increase in the adult size class represents a recovery from overharvest.

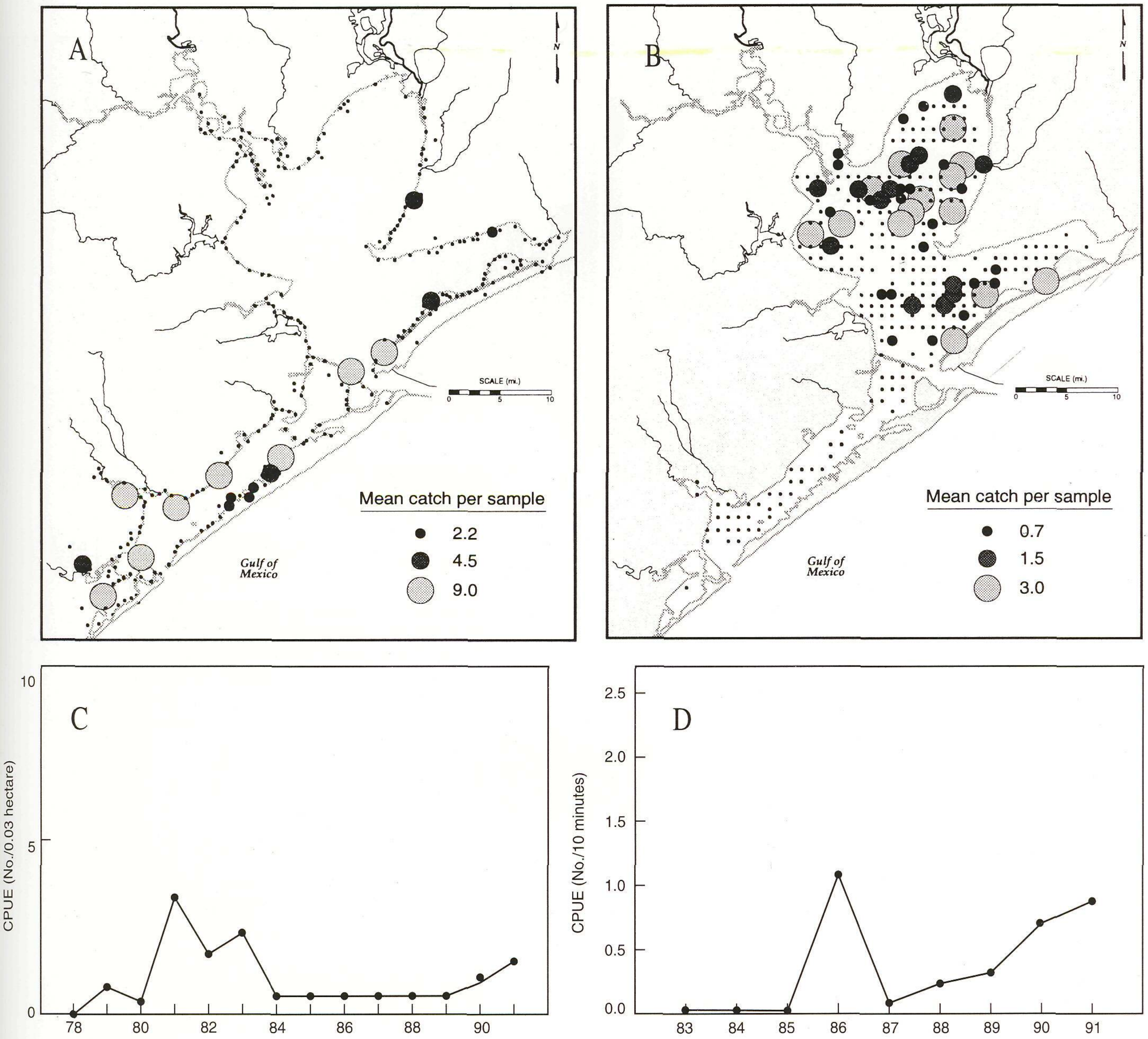
blue crabs are more valuable than females, due to their larger size.

An alternative explanation for the blue crab decline involves a possible decline in the import of organic detritus to the middle and lower portions of the estuary, associated with wetlands loss. Such a loss of detritus could represent a decreased available food supply for the blue crab (Green et al., 1992). The duration of the blue crab population decline prior to 1983 is unknown, as little detailed fisheries information is available for this species. Similar declines have been noted in Aransas Bay and Laguna Madre, although these are much smaller fisheries in terms of total blue crab landings.

Current harvesting regulations include: 1) crab traps must be marked; 2) the number of crab traps per fisherman is restricted in certain areas; 3) egg-bearing females must be released; and small crabs (less than five inches) must be released, except for use as bait.

Red Drum and Spotted Seatrout

Red drum and spotted seatrout are the premier recreational game species of the bay. Both were already in a state of reduced abundance due to overfishing when intensive scientific studies of these populations were initiated. Regulations passed to protect red drum and spotted seatrout included: no commercial sale since 1981; banning of all nets in 1988; implementation of minimum and maximum sizes (maximum limits for red drum only, to protect spawners); and daily bag limits for recreational fishermen in 1982. These species showed increases in first-time spawners and remaining adults after these regulations were implemented, despite several



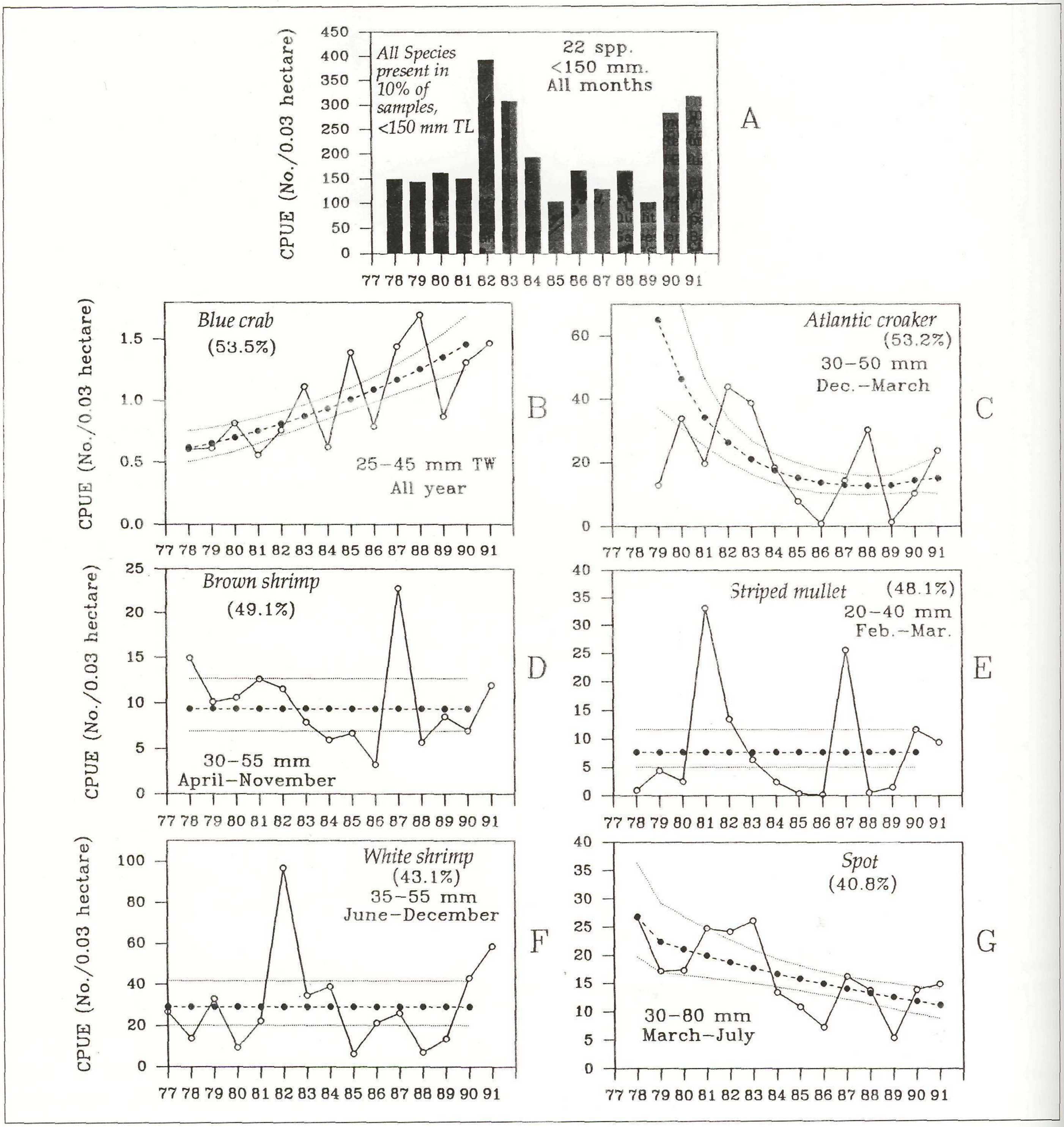
Source: Green et al., 1992

FIGURE 8.9. *Bay anchovy abundance distributions and temporal trends. Juveniles are shown in (a), caught with seines along the shoreline (15-35 mm size, May-October, 1978-1989), while (c) reveals the corresponding abundance trend over time. Young-of-the-year are shown in (b), caught with trawls in open bay waters (15-34 mm size, December-March, 1983-1990), and (d) presents the corresponding time trend. This is likely the most abundant fish in Galveston Bay, providing a major food source for higher level consumers ranging from game fish to birds.*

adverse natural events, including a freeze in 1983, a red tide in 1986, and two more freezes in 1989. Other factors affecting the abundance of these species included migratory patterns, restocking (15-20 percent of red drum originate from hatcheries), illegal netting, and federal management programs.

Young-of-the-year spotted seatrout were found in highest concentrations in Bastrop Bay, Christmas Bay, and the southern shores of West and East Bays (FIGURE 8.8). Relatively large numbers were also caught in some sites in upper and lower Galveston Bay, while Trinity Bay catches were low. First-time spawners were widely distributed, but not as common in Trinity Bay, and were mainly found on the southern shores of West and East Bay and the Bastrop and Chocolate Bay areas. In contrast, large catches of adults occurred throughout the bay system, including the Trinity Bay Area.

Young-of-the-year spotted seatrout decreased in abundance during the study period, while first-time spawners and remaining adults apparently increased, at least in the early years of the study. Loss of nursery habitat may have played a critical role in the decrease of young fish. The slight decrease in recent years of the adult population may reflect random year-to-year variation or a cyclic pattern; alternatively it may indicate a true decrease related to the decrease in juveniles, increasing fishing pressure, or other factors not taken into account in the study.

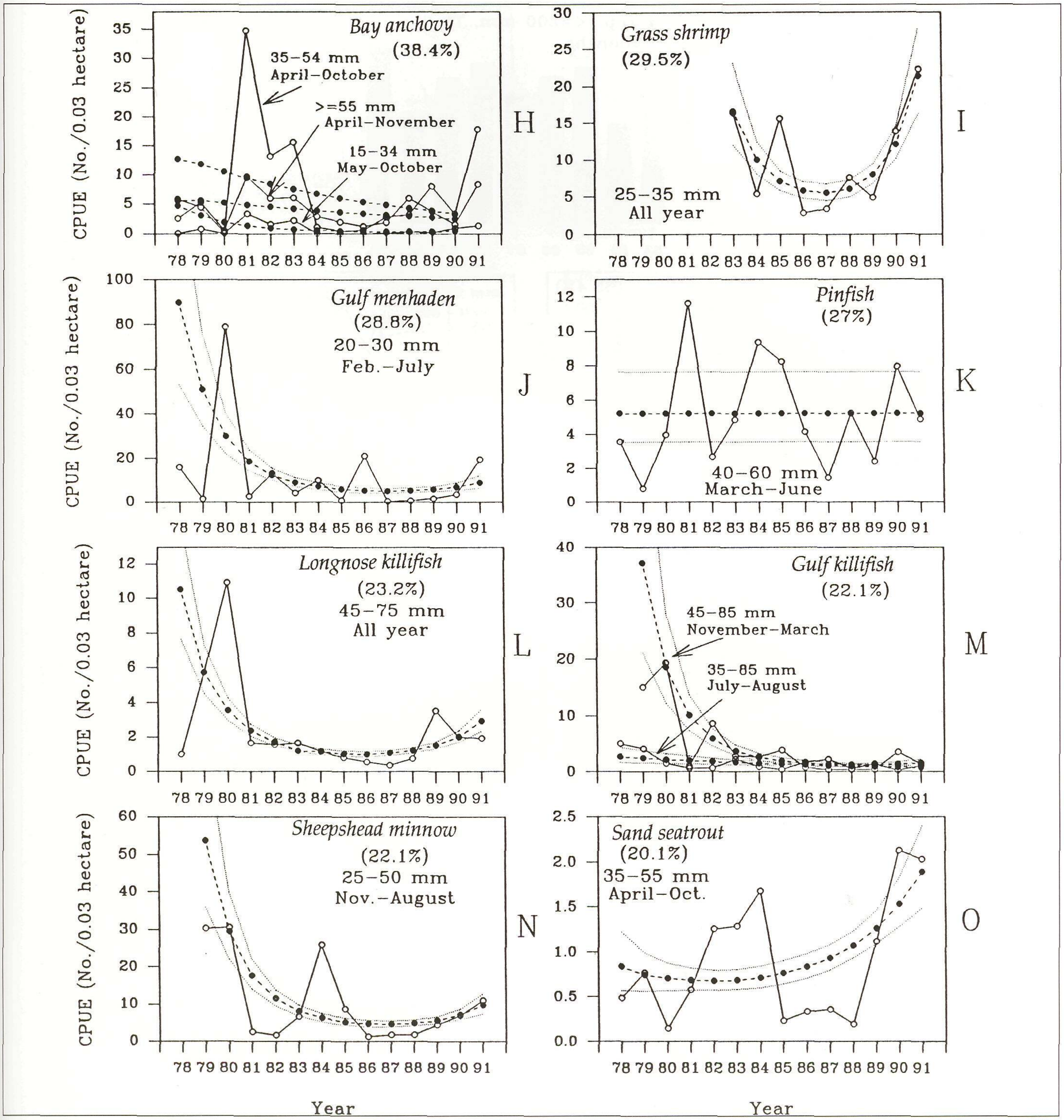


Source: Green et al., 1992

FIGURE 8.10. Mean annual trawl catch per unit effort (CPUE) is shown for fourteen selected species (b-o, including facing page) caught by bag seine, and a time trend for all these species combined is given in (a). Shown on the individual species plots is a trend line (solid dots) and corresponding 95 percent confidence interval. Note size ranges, for comparison to FIGURE 8.11, which includes larger sizes of some of the same species.

In the case of red drum, young-of-the-year were found throughout the estuary with the highest concentrations in Christmas Bay, Bastrop Bay, Chocolate Bay, West Bay, East Bay, around Smith Point, and near the Clear Lake area. The geographic distributions of juvenile and first-time spawning red drum were similar; the highest catches for both size classes were concentrated in East Bay, around Christmas Bay, Bastrop Bay and the northern part of upper Galveston Bay.

The causes of variability for red drum were incompletely understood, but several factors may have been important. Recent losses of protected areas with grass and mud bottoms, important to juveniles, may have exerted an influence. Fluctuations in shrimp,



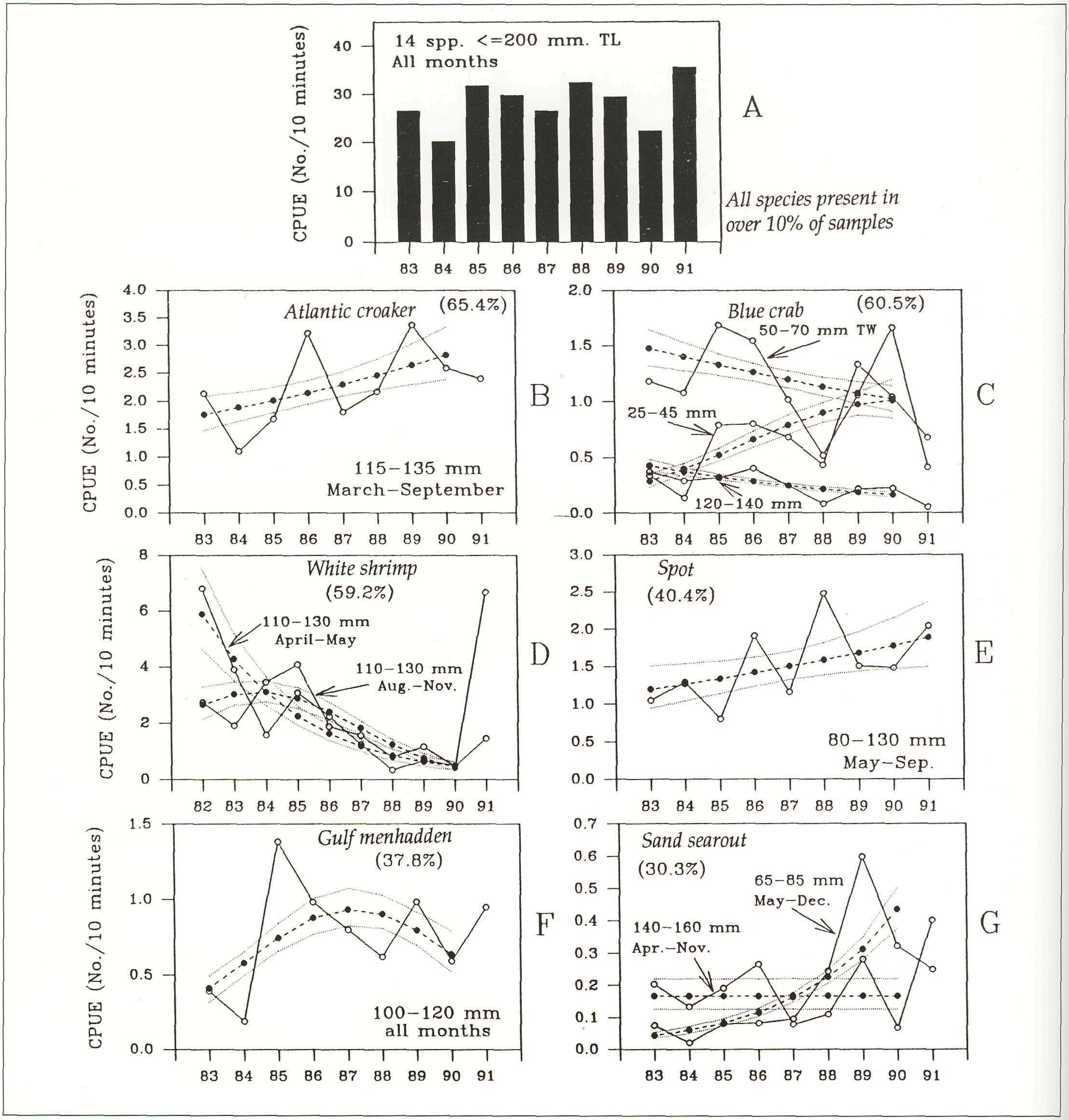
Source: Green et al., 1992

a primary food source, could also have driven changes in numbers. For this species, population trends are further complicated by regulation and stocking efforts to rehabilitate the species. Close to five million red drum fry were stocked in the estuary in 1979, and over one million in 1983, perhaps reflected in the peak catches of young fish in those years and, to some degree, in subsequent peaks in the two larger size classes. However, no such peak appeared in 1985 when over one and a half million fingerlings were stocked, possibly because most of them were released later in the year and were not of sufficient size to be included in the 25–65 mm size range.

Bay Anchovy

Bay anchovy are planktonic feeders which provide an important prey item for larger fish species. Although third in abundance (in terms of numbers of fishes caught) this species is probably the most numerically abundant fish in the bay, prevalent both nearshore and offshore.

The distribution maps for bay anchovy (FIGURE 8.9) reveal

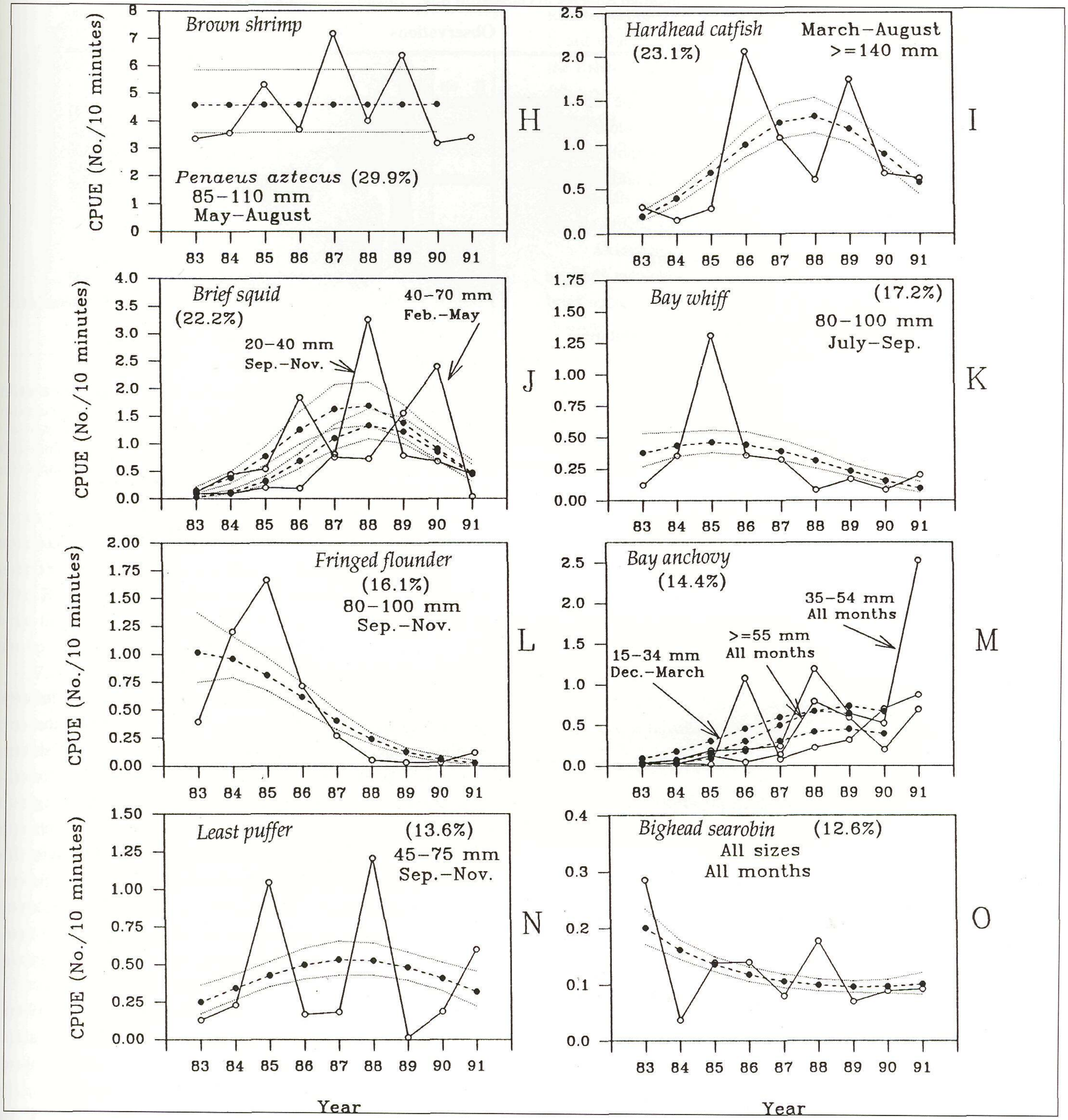


Source: Green et al., 1992

FIGURE 8.11. *Mean annual trawl catch per unit effort (CPUE) is shown for fourteen selected species (b-o, including facing page) caught by bag seine, and a time trend for all these species combined is given in (a). Shown on the individual species plots is a trend line (solid dots) and corresponding 95 percent confidence interval.*

that first-time-spawners (35-54 mm) were associated with bay margins, particularly West Bay and East Bay, while first-time spawners in the open-bay were more abundant in the lower estuary. Changes in seasonality may be partially responsible for the differing results for bag seine CPUEs (warm months analyzed) and trawl CPUEs (cold months analyzed).

When analyzed for temporal trends, three classes of bay anchovy (15-34 mm, 35-54 mm, >55 mm) decreased in population from 1978 to 1990 for the bay margins. In the open bay, however, this fish showed an increasing trend. Once again, these results may be affected by the different time periods that are represented in the analyses done on data from different gear types. Regardless, this



Source: Green et al., 1992

potential decline in a major prey species along the shores, combined with the observed decline for some shore-feeding birds (see page 184), suggests the issue be further investigated.

Striped Mullet

Striped mullet are one of the most abundant fish species in shallow Texas waters. Young mullet use the back-bays of the estuary as nursery areas, where they feed on detritus and epiphytic algae. In Galveston Bay, striped mullet were evenly distributed throughout the bay for both bay margin habitats and the open bay. Young-of-the-year had peaks in the winters of 1981 and 1987 and first-time spawners showed an overall increasing trend. Adults decreased from 1975 to 1979, then remained constant. No mechanisms have been identified to account for these changes.

Other Species

The Texas Parks and Wildlife Department also identified the status and trends for other key indicator species (Green et al., 1992;

TABLE 8.4. Estuarine Fish and Shellfish Species in Galveston Bay: Results of Species Trend Studies

Species	Observations
Apparent Decline:	
Blue Crab	Chronic recent decline for older age classes; intensive harvest likely involved
White Shrimp	Chronic decline for older age classes; overharvest, habitat loss, pollution implicated; apparent very recent population rebound
Grass Shrimp	Strong decrease in adults followed by recent increase; other life stages inconclusive
Striped Bass	Long term decline
Green Turtle	Long term decline
Diamondback Terrapin	Long term decline
No Apparent Trend:	
Brown Shrimp	No apparent consistent trend
Southern Flounder	No significant trend for young of the year or adults
Gulf Menhaden	Variability among age classes and sampling period; no long-term pattern
Pinfish	Variability among gear types and sampling period; no long-term pattern
Bay Anchovy	Different gear types yield conflicting results; possible slight increase 1984-1990
Black Drum	Young of the year decreased 1978-1990; adults increased
Sand Seatrout	Variability among age classes, gear type, and sampling period; no long-term pattern
Apparent Increase:	
Red Drum	General increase in spawners and adults; harvest restrictions likely helped
Spotted Seatrout	General increase in spawners and adults; harvest restrictions likely helped
Atlantic Croaker	Linear increase in adults; no consistent trend for juveniles

Source: Green et al., 1992

Green et al., 1993; FIGURES 8.10–8.11). The most notable trends for Galveston Bay shellfish and finfish are summarized in TABLE 8.4.

Probable Causes of Fish and Shellfish Declines

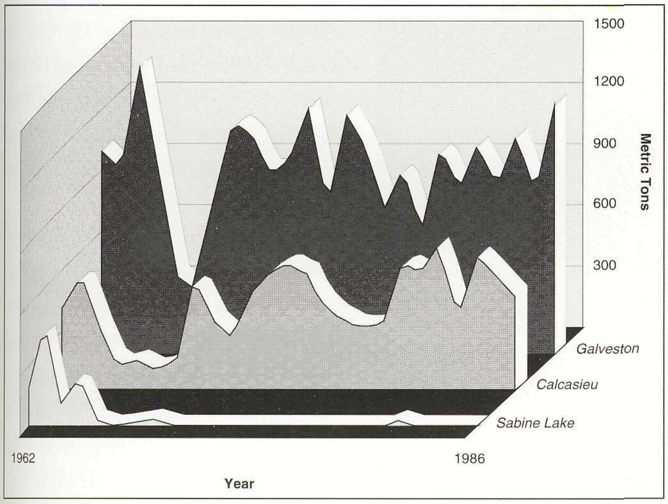
The declines noted above for white shrimp and blue crab populations raise some concerns for these species and for potential bay conditions which may have influenced the declines (Walton and Green, 1993). In addition, anecdotal information exists for several other species (such as tarpon, snook, and striped bass), indicating long-term declines compared to 1800s levels. Some reasons for declines were discussed above, such as overfishing, loss of marsh habitat, changes in fresh water inflow, and changes in riverine organic loads to the bay.

Below, the role of wetlands and fresh water inflow is addressed in more detail. In addition, several other studies have been performed to evaluate various impacts on Galveston Bay's living resources from commercial and recreational **bycatch**, cooling water systems, fish kills, and pollution in the Houston Ship Channel. Currently, there is little information to quantitatively link mortality from any of these sources to population limitations of species bay-wide, but clearly the magnitude of the impacts from some of these sources could have important effects.

The Role of Wetlands and Fresh Water Inflow

Future changes in fresh water inflow could potentially have a great effect on shrimp populations. High fresh water inflows result in increased nutrient availability and diatom blooms that can sometimes be associated with increases in brown and white shrimp populations (Walton and Green, 1993; Gunter and Hildebrand, 1954; and Gunter and Edwards, 1969). In Sabine Lake, changes to inflow resulting from damming the Neches and Sabine rivers and concurrent isolation of wetlands may have been responsible for the permanent collapse of a 300 metric ton/year white shrimp fishery in Sabine Lake (Sheridan et al., 1989). At the time of collapse, comparable fisheries in Galveston Bay and Lake Calcasieu were not affected (FIGURE 8.12). Possibly acting through a climatic link to inflow, a correlation has also been observed between El Niño events and higher shrimp productivity (Green et al., 1993), but no causative relationships have been confirmed. It remains uncertain how global climatic events like El Niño or the Southern Ocean Oscillation Event affect estuarine organisms locally.

Future wetland losses are also a concern for shrimp. In nearshore Louisiana, a decline in landings of brown shrimp was directly linked to the loss of nearby salt marsh (Turner, 1977). But paradoxically, increased populations of some aquatic organisms over the long-term record (i.e. over the last 30 years) may also reflect the long-term loss in wetlands. A relative sea-level rise (i.e. a "drowning" marsh) temporarily increases access to marsh areas for many species with a corresponding temporary increase in secondary production when compared to stable marshes. This can be seen in the long-term recruitment trends of several commercial



Source: Sheridan et al., 1989

FIGURE 8.12. The permanent collapse of the white shrimp fishery in Sabine Lake resulted from diversion of the Neches and Sabine Rivers (altering fresh water inflow), and isolation of wetlands serving as critical nursery areas. White shrimp production in Sabine Lake is compared to Galveston Bay and Lake Calcasieu during the same period.

species: Gulf-wide harvesting of young Gulf menhaden has increased over 200 percent in the past 30 years while populations of young shrimp have increased over 50 percent (Sheridan et al., 1989). Based partially on these results, Sheridan et al. (1989) concluded that "the effects of marsh disintegration are beginning to show up."

Valuable fisheries and wildlife habitat has been lost in Galveston Bay due to an apparent rise in sea level (on the order of 1.5 to two feet since the turn of the century–see Chapter Five) in combination with surface subsidence caused by pumping of oil and groundwater. While most of the near-shore and bay bottom subsidence has all but stopped, the Environmental Protection Agency has predicted that a general sea level rise will continue, perhaps at an increased rate. If this predicted sea level rise occurs, then much more marsh will be lost than is gained by the rising water level. The net loss of marsh would be due to local topography and the presence of urbanization that would prevent the conversion of low-lying upland areas to marsh (FIGURE 8.13).

Shrimp Trawl Bycatch

Bycatch is a broad term to describe unwanted incidental harvesting of organisms during pursuit of a different species. A recent study to assess shrimp trawl bycatch in Galveston Bay was conducted by the National Marine Fisheries Service Galveston Laboratory during the 1992 shrimp season (Nance et al., 1993).

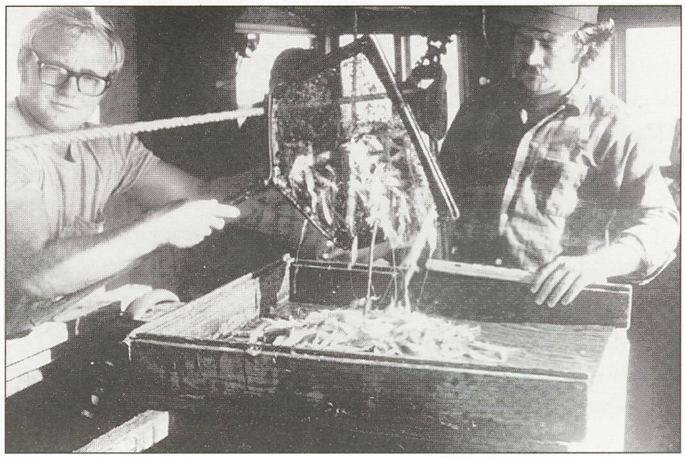
Both commercial and bait fishing industries were evaluated. Overall, one fish was captured as incidental bycatch for every 1.9 shrimp landed during the March to November shrimping season. In terms of biomass, 2.6 kg of fish were collected for every one kg of shrimp. By using shrimp landings data, the total bycatch from shrimping (fish plus crabs and squid) in the Galveston Bay system was estimated at about four million kg during the 1992 fishing season.

These bycatch data represented the sum of all fish and invertebrates captured in the shrimp trawls, including those culled overboard which survived in some unknown proportion. Almost all of the fishermen who participated in this study utilized culling boxes (plywood enclosures with flow-through seawater) on their vessels. The catch from each net haul was generally placed in these culling boxes to minimize mortality of live-bait shrimp being sought (bait operations) and facilitate ease of separating shrimp from bycatch. No specific tests were performed to determine the survival rate of the discarded organisms.

Dominant bycatch species captured included Atlantic croaker, Gulf menhaden, sand seatrout, bay anchovy, sea catfish, spot, brief squid, and blue crab. Recreational finfish species (southern flounder, red drum, and spotted seatrout) were captured infrequently in shrimp trawls, a conclusion supported by previous studies.

Recreational Bycatch

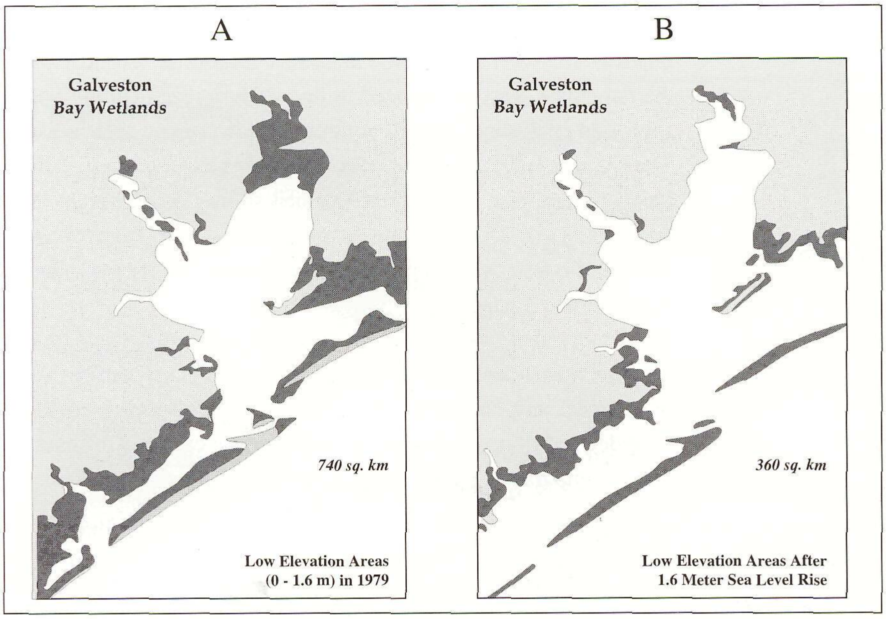
Based on federal and state fisheries data, Saul et al. (1992) concluded that recreational sport-boat fishermen caught and released about two fish for every fish retained. When applied to the



Source: Texas Parks and Wildlife Department

About three pounds of bycatch (fish and other non-target species) are caught for each pound of shrimp harvested. The net haul (below) is culled on board (above), with the bycatch returned to the bay.

Source: Texas Sea Grant College Program



Source: Sheridan et al., 1989

FIGURE 8.13. Predicted changes in wetland areas if a 1.6-m sea level rise occurs. Wetlands in 1979 (a) are compared to a predicted condition in the year 2100 (b).

entire Galveston Bay system, about 1.2 to 3.5 million fish are caught and released each year. Approximately five percent of the released fishes were reported as being released dead. Available literature on hooking and handling mortality suggests that less than 15 percent of red drum released alive and up to 30 percent of spotted seatrout released alive, die from injuries or stresses related to capture within seven days of being hooked, handled, and released. Although total biomass of recreational bycatch (including survivors) was not estimated by Saul et al., it is probably around 1-2 million kg/yr, or less than half the total shrimp bycatch biomass of four million kg/yr (assuming recreational bycatch of an average of 2.4 million fish/yr at an estimated 0.5-1 kg/fish).

Impacts From Cooling Water Systems

Cooling water systems for such industries as power generation can cause incidental mortality of bay organisms through **impingement** and **entrainment**. Impingement occurs when organisms are collected by a screen at a water intake structure. Entrainment occurs when organisms too small to be intercepted at the intake screens pass through the plant. There are five major electricity generation facilities around Galveston Bay operating cooling water systems, each of which utilize U.S. Environmental Protection Agency-defined "Best Available Technology" impingement and entrainment control systems. Such systems control impingement and entrainment losses by limiting the approach velocity of the water to the intake screens, and by providing a pathway for the larger organisms to be diverted around the plant.

The impact of cooling water use on fishery resources was studied using historical data (Palafox and Wolford, 1993). Using 1978-1979 data from five HL&P generating plants located on Galveston Bay, they concluded that about 84 million organisms representing a total biomass of 477,000 kg were impinged each year at the five HL&P plants located on Galveston Bay. They also concluded that only one other facility besides the five HL&P generating stations (a chemical facility in Texas City) could have a major effect on finfish and shellfish in the bay due to impingement.

To gauge the relative significance of impingement, Palafox and Wolford (1993) compared the projected biomass of sport and commercial species impinged at five HL&P plants to the biomass of commercial and sportfish landings reported by the Texas Parks and Wildlife Department. The 1978 to 1979 time period had the most extensive data for comparison. For the species of interest, more biomass was landed by commercial and recreational fisherman than were impinged on the cooling system screens. The weight of impinged brown shrimp and white shrimp was nearly 11 percent of the commercial landing, while impinged blue crabs from these locations represented nearly 17 percent of the commercial landings bay-wide. The weight of red drum, sand seatrout, and spotted seatrout were all less than three percent of the recreational landings. In general, commercially and recreationally

Source: Texas Parks and Wildlife Department

Four of the top ten Coastal fish kills reported in the nation 1980-1989 occurred in the Galveston Bay system, with 50 million fish killed in a single event. The typical kill occurs in an area of limited circulation in the warm months. The predominant cause is lack of oxygen, not toxicity.

important species such as spotted seatrout, black drum, red drum, and southern flounder were infrequently impinged and only in low quantities.

It should be noted that the above comparison of commercial and sportfish landings to entrainment levels does not consider survival rates of entrained organisms. The data show considerable but varied survival, depending on species, time of day, season, and plant location. In particular, plant location clearly affected survival rates: survival at the Cedar Bayou station was much greater than the survival rates reported for the Robinson station near San Leon. In general, crustaceans had higher survival rates than fish.

Source: Frank S. Shipley

Shorebirds and this pair of pintail ducks are just a few of the bird species which depend upon the habitats provided by Galveston Bay.

None of the historical studies used to develop these conclusions focused on the overall scope of cooling water impingement and entrainment. In particular, there may be considerable environmental impact on marine eggs, larva, and other juvenile organisms drawn through the cooling systems.

Both detrimental and beneficial effects were observed from the discharge of heated effluent from the Cedar Bayou Generating Station. Gulf menhaden showed negative effects from elevated temperatures of 30°C, and bay anchovy, sea catfish, sand seatrout, and spot avoided zones with water temperatures greater than 35°C. On the other hand, large numbers of fish were found congregated in the discharge canal and near the outfall during the winter (Palafox and Wolford, 1993).

Fish Kills

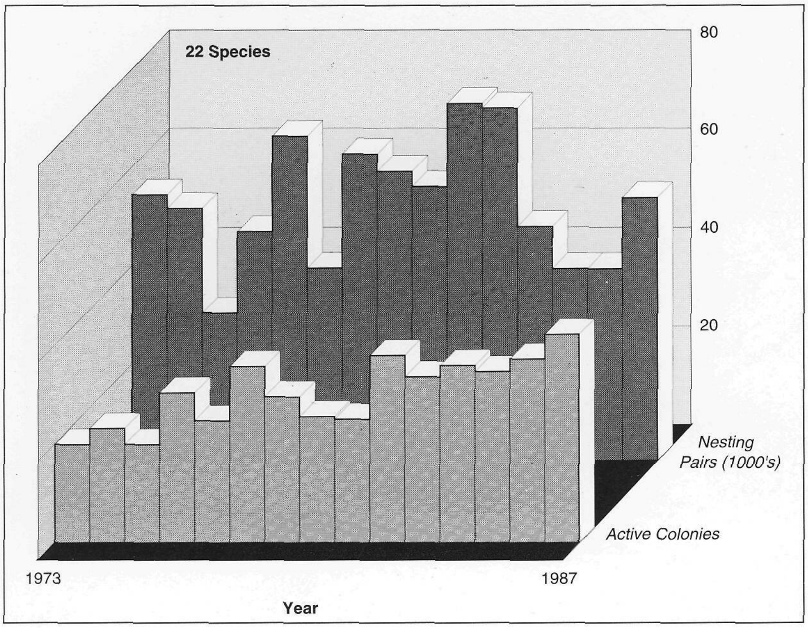
The Gulf Coast has some of the nation's largest and most frequent fish kill events, partially because of the hot climate and physical features such as low circulation. In a national study, Galveston Bay had the highest number of reported major fish kills (28) in the United States from 1980 to 1989 (Lowe et al., 1991) with over 100 million fish killed. Seventeen of the 28 kills were related to low dissolved oxygen.

Palafox and Wolford (1993) reviewed 220 Galveston Bay fish kills which occurred over the past 20 years, with the following findings:

> Fifty-six fish kills (25 percent) were related to point source pollution. Primary causes were unknown spills at electric power generation facilities, sewage treatment plant by-passes, pipeline leaks and unknown spills at chemical plants, ocean dumping, and seismic detonations. Almost all of the fish mortality attributed to point sources occurred from May to October, with peaks in May and September.
>
> Forty-three kills (20 percent) were caused by nonpoint sources, including undefined runoff events and other nonpoint influences contributing to low dissolved oxygen. Gulf menhaden was the species most often killed in nonpoint source events. These occurred most often from June through September with a peak in August.

TABLE 8.5. Dominant Species in the Upper Houston Ship Channel.

Common Name	Scientific Name
Brown shrimp	*Penaeus aztecus*
White shrimp	*Penaeus setiferus*
Grass shrimp	*Palaemonetes pugio*
Blue crab	*Callinectes sapidus*
Gulf menhaden	*Brevoortia patronus*
Threadfin shad	*Dorosoma petenese*
Bay anchovy	*Anchoa mitchilli*
Sheepshead minnow	*Cyprinodon variegatus*
Gulf killifish	*Fundulus grandis*
Longnose killifish	*Fundulus similis*
Inland silverside	*Menidia beryllina*
Spot	*Leiostomus xanthurus*
Atlantic croaker	*Micropogonias undulatus*
Striped mullet	*Mugil cephalus*
White mullet	*Mugil curema*
Sailfin molly	*Poecilia latipinna*



Source: Sheridan et al., 1989

FIGURE 8.14. Trends for colonial nesting birds. These species include the herons and ibises, terns, cormorants, roseate spoon bill, and black skimmer.

One hundred and twenty-one fish kills (55 percent) could not be classified as to cause based on the report records.

Fish kills most often occurred in tributaries to Clear Lake and East Bay, and within West Bay, San Jacinto Bay, Dickinson Bayou, and Clear Lake. Although fish kills from freezes can be significant, these kills were not included in the references presented above.

The Upper Houston Ship Channel–Biological Suitability

Early studies of the Houston Ship Channel determined that the area above the confluence of the San Jacinto River was virtually lifeless (Chambers, 1960). By the mid 1970s, considerable improvement could be seen between the San Jacinto River and Greens Bayou (Segment 1006), but the upper portion from Greens Bayou to the Turning Basin (Segment 1007) was still devoid of fishes, crabs, and shrimps.

Since the late 1960s, municipal and industrial point source waste loadings of BOD have decreased by over 95 percent (see Chapter Six), resulting in utilization of the channel by a variety of organisms (Seiler et al., 1991). The lower portion of the landlocked reach now supports a viable fish population year-round (TABLE 8.5). In the winter, the upper channel has a species richness and abundance that exceeds the lower portion of the landlocked reach, and it also maintains a viable shoreline assemblage during the summer months. Seiler et al. (1991) also concluded that although the upper Houston Ship Channel currently possesses a "no aquatic life" designation, the increased utilization by fish, shrimp, and crabs may have implications on the future use designations of the channel.

The return of estuarine species to the upper Houston Ship Channel is encouraging, but does not indicate a complete recovery to conditions characteristic of other portions of the bay. Biological diversity remains generally lower, dissolved oxygen is still depressed (particularly near the bottom) and toxic contamination of sediments and organisms continues to be observed.

BIRDS

Bird populations in Galveston Bay have significant commercial, recreational, ecological, and aesthetic values. In addition, many bird species are predators on fish, shellfish, or benthic organisms, and therefore are important indicators of the health of the food web and the status of different bay habitats.

Observers have noted 139 bird species associated with Galveston Bay wetlands and open-bay habitats (Arnold, 1984).

Source: Robert W. McFarlane

Source: Robert W. McFarlane

Forester's terns nest in a smooth cordgrass marsh on a dredged-material disposal island in Drum Bay (left). The wind- and wave-driven wrack composed of hollow, jointed cordgrass stems lodges in the marsh and provides a dry platform for nests (right). The nests and underlying wrack float up and down with the tide but can float free and blow away on exceptionally high storm tides.

TABLE 8.6. Estuarine-Dependent Bird Species Utilizing Galveston Bay: Results of Species Trend Studies.

Species	Observations
Apparent Decline:	
Tricolored Heron	Fewer total birds nesting in more colonies; no trend in the Christmas Bird Count
Snowy Egret	Decrease in numbers and numbers per nesting colony; Christmas Bird Count showed increase
Black Skimmer	Decrease in numbers and numbers per nesting colony; no trend in the Christmas Bird Count
Roseate Spoonbill	Decrease in numbers and numbers per nesting colony; Christmas Bird Count showed increase
Mottled Duck	Mid-winter Waterfowl Transects showed decrease; Christmas Bird Count showed increase
Northern Pintail	Mid-winter Waterfowl Transects showed decrease; Christmas Bird Count showed increase
Blue-winged Teal	Mid-winter Waterfowl Transects showed decrease; Christmas Bird Count showed increase
No Apparent Trend:	
Great Egret	Constant or increasing total number nesting in more colonies with fewer birds
American Avocet	No change on Bolivar Flats Survey; increase in Christmas Bird Count
Dunlin	No change on Bolivar Flats Survey; increase in Christmas Bird Count
American Coot	No discernible trend
Green-winged Teal	No discernible trend
Northern Shoveler	No apparent trend; variability suggests local movements
American Widgeon	No apparent trend; variability suggests local movements
Canvasback	No trend based on Christmas Bird Count
Fulvous Whistling Duck	No trend based on Christmas Bird Count
All Blackbirds	No trend or insufficient data
Apparent Increase:	
Olivaceous Cormorant	Increase in total numbers and colonies; Christmas Bird Count showed variable increase
Forster's Tern	Increase in colonies and Christmas Bird Count
Black-bellied Plover	Apparent increase based on Bolivar Flats Survey and Christmas Bird Count
Willet	Apparent increase based on Bolivar Flats Survey and Christmas Bird Count
Sanderling	Apparent increase based on Bolivar Flats Survey and Christmas Bird Count
Western Sandpiper	Apparent increase based on Bolivar Flats Survey and Christmas Bird Count
Mallard	No change or possible increase in wintering population
Gadwall	No change or possible increase in wintering population
All Scaup	Christmas Bird Count showed increase
Ruddy Duck	Christmas Bird Count showed increase
Bufflehead	Christmas Bird Count showed increase
Wood Duck	Christmas Bird Count showed increase
Ring-necked Duck	Christmas Bird Count showed increase
Black-crowned Night Heron	Increase in colonies and Christmas Bird Count

Source: Green et al., 1992

TABLE 8.7. Colonial Waterbird Nesting Locations in Brazoria, Chambers, Galveston and Harris Counties for 1990.

Colony Name	Number of Species	Number of Breeding Pairs
Brazoria County		
Follets Island	2	70
Drum Bay	10	470
Bastrop Bay	2	120
West Bay Bird Island	4	215
San Luis Island # 1	0	0
Arcadia Reef	5	125
Chambers County		
Catfish Acres	5	870
Trinity River Mouth	6	3,320
East of Lost Lake	4	425
Vingt-et-un Island	9	380
Galveston County		
Scholes Field	1	80
Redfish Island	2	42
Smith Point Island	12	1,602
Rollover Pass	10	1,438
Moses Lake Spoil Islands	4	82
Dickinson Bay Spoil Island	2	550
Bolivar Flats	1	2
Marker 52 Spoil Island	1	30
Jigsaw Island	2	270
North Deer Island	14	4,829
Down Deer Island	1	70
South Deer Island	7	620
Ganges Bayou	1	62
Little Pelican Island	15	15,574
Pelican Island	4	10,448
Fort San Jacinto	1	4
Magnolia Compress #15	1	4
Farmers Copper	1	50
McAllis Point	1	20
Maggies Point	3	230
Snake Cove Point	2	26
Bay Harbor Bar	4	330
Oxen Bayou Point	2	90
Mensell Bayou Point	6	823
Starvation Point	2	17
Eckert Bayou Point	4	613
Hoeckers Point	2	85
Dana Cove	1	25
Carancahua Cove	6	682
Live Oak Grove	1	4
San Luis Pass	2	210
Harris County		
Sheldon Reservoir	5	1,110
Baytown Tunnel	2	60
Alexander Island	10	793
Exxon Baytown North Gate	1	32

Source: Jones and Neuse, Inc., 1992

Data from the Texas Colonial Waterbird Surveys from 1973 to 1990 were used to evaluate trends for birds utilizing Galveston Bay living resources and habitats. The Christmas Bird Count represented another source of data. The Christmas Bird Count is a winter bird census conducted by the Audubon Society, utilizing amateurs to enumerate birds in prescribed areas. Population trends for colonial waterbirds, waterfowl, shorebirds, and special species of interest were summarized from three primary sources: Walton and Green (1993), Slack et al. (in Green et al., 1992), and Sheridan et al. (1989). TABLE 8.6 summarizes the overall trends for different birds of the Galveston Bay estuary.

Colonial Waterbirds

Overall, there is no significant trend in the number of total colonial waterbirds around Galveston Bay, nor is there a trend in number of species present from 1973 to 1990. The number of pairs of colonial-nesting waterbirds has varied from about 39,000 pairs in 1978 and 1982 to a high of 71,200 in 1985 (FIGURE 8.14). The number of active colonies, found in association with gravel and shell bars, marshes, cypress stands, dredged material islands, and industrial and developed locations, has increased from 20 in 1973 to 42 in 1987 (see TABLE 8.7 for data from 1990). The three most common species in the 1986 nesting season were the laughing gull, royal tern, and cattle egret.

The results of this overall analysis, while encouraging, could potentially obscure patterns of concern for individual species. An analysis performed in 1992 indicated that some particular colonial species were indeed declining in numbers (Slack et al. in Green et al., 1992). Subsequently, Slack et al. performed a more detailed statistical analysis which identified a long-term structural change in Galveston Bay's bird community (Green et al., 1992; Walton and Green, 1993). Population trends for three different groups of colonial waterbirds were evaluated: 1) an inland species group, 2) an open-water group, and 3) a marsh group.

The inland group consisted of fresh water marsh feeders and generalists such as little blue herons, white ibises, cattle egrets, white-faced ibises, and great blue herons. No significant change in number of individuals or percentages of these birds in colonies was observed during the period 1973-1990.

Open-water birds included royal terns, Caspian terns, olivaceous cormorants, Forster's terns, and Sandwich terns. These species depend primarily upon fish caught from open-bay habitats. Both the number of individuals and number of colonies increased during the study period.

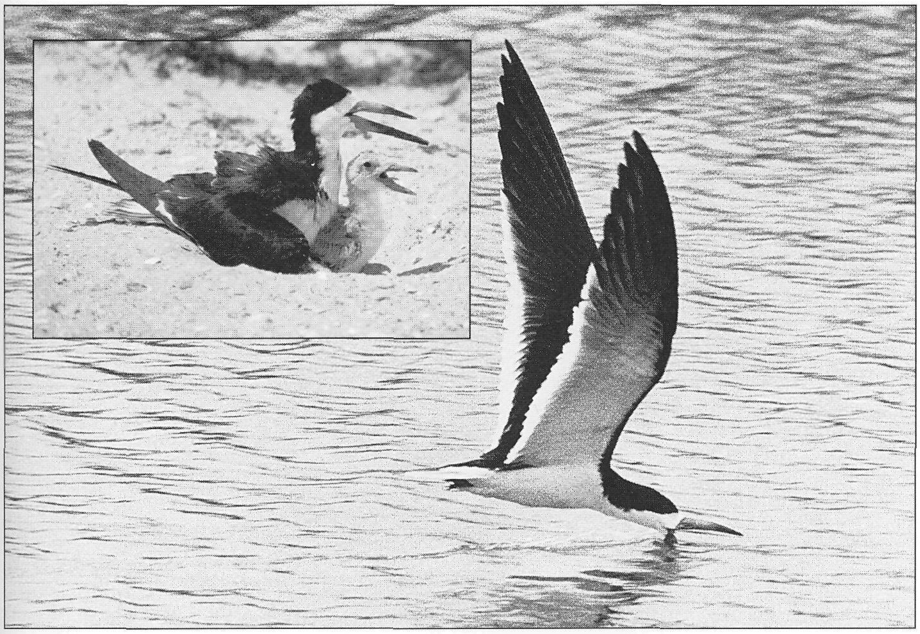
Species in the marsh group were waders that feed on small fish and benthic invertebrates along shoreline marsh edges. Species included snowy egrets, roseate spoonbills, tricolored herons, black skimmers, and great egrets. For these species, the number of colonies increased, but number of individuals per colony decreased enough to represent an overall decline in numbers. This decline is of particular concern in view of the 17-19 percent reduction in wetlands needed by these species (Chapter Seven). These species nest in colonies but spread out within the bay system for feeding. Nesting colony locations are ample, but the feeding habitat losses may have influenced populations.

Waterfowl

An annual average of 11,500 waterfowl were observed in the Galveston Bay system, based upon data for 1978 and 1984-1987 (Sheridan et al., 1989). The most commonly observed species were all migratory: the green-winged teal, ring-necked duck, lesser scaup, red-breasted merganser, and ruddy duck. Because of the nature of these and other migratory species, population regulation is impossible to evaluate by studying populations at any one location. That is, they could be winter-limited (influenced by conditions in Galveston Bay and other wintering areas) or breeding-limited by habitat or other factors to the north. However, reductions in numbers utilizing a winter area, while not necessarily reflecting population reductions, could nevertheless reflect decreased habitat utilization in response to habitat loss or deterioration.

Migratory waterfowl such as northern pintail and blue-winged teal have declined in population continent-wide, most probably due to loss of wetland breeding habitat on the Great Plains, or conditions in the Central and South American wintering grounds. Texas-related factors for the decline in these species are therefore difficult to evaluate (Cain and Feierabend, 1988). Controls on pesticide use have reduced pesticide-related mortality, while avian cholera mortalities increased in the 1980s. Poisoning from lead shot is a problem for some species, such as mottled duck (Moultan et al., 1988), although steel shot is now exclusively used in the coastal area.

Only the fulvous whistling duck, mottled duck, and wood duck breed in the vicinity of the bay system. Data on mottled duck populations were somewhat contradictory. The long-term Christmas Bird Count data indicated a generally flat trend line from 1964 to 1989, while the Texas Parks and Wildlife Department and U. S. Fish and Wildlife Service Mid-Winter Waterfowl Survey shows a strong downward trend for the period 1986 to 1991 (Slack et al. in Green et al., 1992). Part of the reason for the discrepancy is the large scatter shown in the data, particularly for the Mid-Winter Waterfowl Survey. Additional data are required to confirm which surveys are more representative of actual mottled duck population trends.



Source: Frank S. Shipley; inset Robert W. McFarlane

Black skimmers utilize the unique foraging method of skimming the water surface in flight. Inset is an adult with its chick and simple nest scrap on a sand-and-shell beach at San Luis Pass on Galveston Island.

While some species of ducks have declined, geese populations have increased. Geese are more efficient at using winter rice fields and other uplands for their food supply, and they are adaptable to a variety of breeding habitats (Bateman et al., 1988). Snow geese may be increasing to the point where populations will be affected by overcrowded breeding grounds.

Shorebirds

The Galveston Bay system has been identified as a regionally significant reserve site for migrating shorebirds, and supports more than five percent of all mid-continental shorebird populations during their annual migrations. Many of these species are probers, inserting their elongated bills into the sediments to capture benthic infauna on the intertidal mud flats and associated shallow-water areas. One species, the American avocet, sweeps the water surface for plankton in the shallows. Intertidal flats on Bolivar Peninsula and on either end of Galveston Island are the primary habitats for these shorebirds.

The most common shorebirds are the black-bellied plover, American avocet, willet, sanderling, western sandpiper, dunlin, and dowitchers (see photo page 186). The Christmas Bird Counts and the Bolivar Flats Shorebird Survey (special surveys conducted by the U. S. Fish and Wildlife Service's Clear Lake Office) indicate a possible increase in shorebirds, although the data are difficult to interpret due to lack of standardization.

Threatened or Endangered Bird Species

Brown pelicans, an endangered species which declined in the 1960s due to the toxicity and bioconcentration of pesticides, have shown increases in Galveston Bay during the past few years, probably because of the reduction/and or elimination of specific pesticides known to be harmful. Two roosting sites, but no nesting sites, are known according to the 1990 Colonial Water Bird Survey. The bald eagle, an endangered species, has nesting sites in Chambers, Galveston, and Harris counties. The arctic peregrine

Source: Frank S. Shipley

Four shorebird species of Galveston Bay (clockwise from upper left): the black-necked stilt, stilt sandpiper, long-billed dowitcher, and dunlin. These and other shorebird species utilize mudflat habitats such as Bolivar Flats in migration.

falcon and piping plover are listed as threatened in some of the counties around the bay, but do not nest in the area.

AMPHIBIANS AND REPTILES

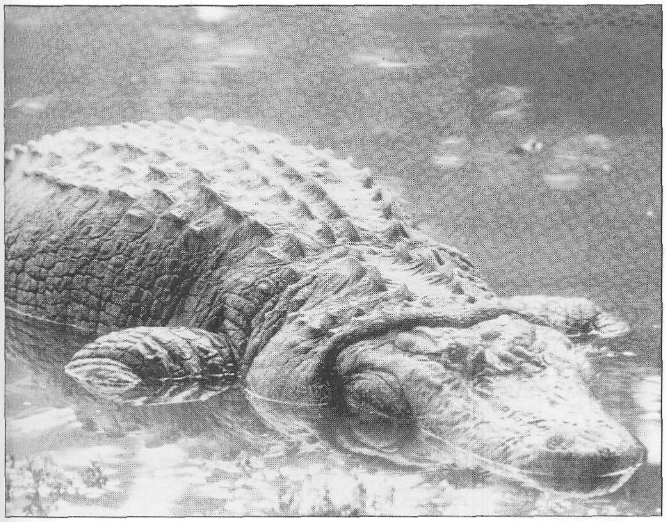
A total of 92 species of amphibians and reptiles have been observed in four counties adjacent to Galveston Bay. Of particular interest is the American alligator, which has increased in population since counts were initiated in 1971. The alligator has increased throughout much of its U. S. range, due to initial harvest bans, followed by reinstated, limited harvests as populations increased. In Texas, harvest has been overseen by the Texas Parks and Wildlife Department. During 1984 to 1986, 655 alligators were legally harvested from the Galveston Bay system, with most taken from the fresh water marshes in Chambers County.

Sea turtles were once present in the bay in relatively large numbers and supported a commercial fishery in Galveston in the 1890s. Today, sea turtles that reside in Texas waters have been identified as threatened or endangered species: leatherback sea turtle, Kemp's ridley sea turtle, loggerhead sea turtle, and green sea turtle. During the 1980-1991 period, a total of 27 sea turtles were found in Galveston Bay (Caillouet et al., 1991). Eighteen sightings were observations of dead stranded turtles, with three turtles found in shrimp trawls. Sightings were concentrated around Bolivar Roads and the Texas City Dike, the San Luis Pass/Chocolate Bay/Christmas Bay area, and Rollover Pass. Kemp's ridley sea turtle comprised 16 of the 27 sightings.

Little is known about the behavior and habitat selection of Texas sea turtles. Currently, the National Marine Fisheries Service is using satellite, radio, and sonic tracking of sea turtles in estuarine and offshore waters to provide more data on turtle biology. Management activities of interest include special precautions prior to marine seismic blasting, use of **turtle excluder devices** (TEDs) by shrimp trawlers, and the National Marine Fishery Service Head Start Program, a recently terminated program to hatch, rear, and release young sea turtles.

MAMMALS

Land mammals that inhabit wetlands around Galveston Bay include the swamp rabbit, gray squirrel, beaver, muskrat, roof rat, northern rice rat, nutria, raccoon, mink, and river otter. Nutria, a species introduced from South America via Louisiana, has been identified as a particular management problem for some of the



Source: Texas Parks and Wildlife Department

Increasing numbers of alligators throughout the southern U.S. have brought the species back from remnant populations. Alligators are now harvested in an open season in Texas, their high numbers even supporting "Gatorfest," an annual extravaganza in Chambers county, where most alligators in the Galveston Bay area are found.

bay's wetlands. Nutria can consume large amounts of the emergent vegetation in wetlands, contribute to wetland loss, and can hinder wetland creation efforts in the area.

About 100 bottlenose dolphins are permanent residents of Galveston Bay and reside primarily around Bolivar Roads (Wursig and Henningsen, 1991). Many more dolphins are transient users of the bay, and over 1,000 different individuals have been observed in Galveston Bay during the past four years.

Based largely on research from Sarasota Bay, Florida, dolphins consume about 3.5-5 percent of their body weight in fish per day, with striped mullet being the primary prey. Assuming an average body weight of 180 kg, a single dolphin is estimated to consume almost 2800 kg of fish per year. When this value is applied to Galveston Bay dolphins, it is estimated that the 100 year-round residents of the bay could consume about 280,000 kg of fish per year.

SUMMARY

A wide variety of fish, wildlife, plant, and invertebrate populations either reside in or periodically utilize Galveston Bay and its associated habitats. These species compose the estuary's food web, capturing solar energy in the carbon bonds of carbohydrate compounds (green plants) thereby creating the food supply for higher level consumers and predators, including humans. The detrital pathway, with decaying organic matter at its base, is an important part of this process.

Most of the Bay's species appear to be in good health, with some exceptions posing management concerns. Phytoplankton abundance has changed significantly through the years, apparently in response to increases in nutrients peaking in the late 1960s, followed by nutrient reductions due to improved pollution control and the construction of reservoirs on the Trinity and San Jacinto Rivers. Today, plankton abundance is similar to levels seen prior to the major urban expansion on the bay's western shores.

Benthic communities have excellent value as indicators of environmental stress. This stress is evident in some Galveston Bay locations due to urban/industrial runoff and petroleum production facilities which discharge toxic compounds. Over wide expanses of the bay, however, the benthic community remains abundant and diverse, following a natural gradient of increasing diversity from the upper bay system seaward. Oyster reefs, if anything, have expanded in recent years. Some of the most productive reefs now occur on the shoulders of the open-bay reach of the Houston Ship Channel, where current velocities and salinity structure favor reef development.

Commercial fish and shellfish populations are generally stable, and fish, crabs, and shrimp have partially reestablished themselves in the once-lifeless Houston Ship Channel following significant reductions in municipal and industrial discharges. However, two species, white shrimp and blue crab, appear to be suffering from commercial overfishing. The Texas Parks and Wildlife Department has responded by banning the harvesting of shrimp in areas where white shrimp are believed to spawn during two crucial summer months, and is considering new fishing limitations for blue crabs. The rebound of red drum and spotted seatrout populations clearly show that Texas fisheries harvest and restocking programs can work.

The total number of all colonial waterbirds has remained relatively stable since the early 1980s. However, the composition of the colonial waterbird community is thought to be changing–there are now fewer wading marsh feeders. In this regard, birds are a sensitive indicator; continued wetlands loss from human development and from relative sea-level rise could greatly reduce the biological abundance and diversity of the bay in the future. As discussed in Chapter Seven, these processes have been responsible for most of the 17-19 percent loss in wetland areas that has occurred since the mid 1950s.

Source: Texas Parks and Wildlife Department

Nutria are an exotic species introduced into the United States from South America. Originally imported for their fur-bearing value, these animals rapidly spread through Gulf Coast wetlands where they encountered few predators. Voracious herbivores, they frequently decimate valuable emergent marsh habitat. Such "eat-outs" leave the sediment exposed and susceptible to high rates of erosion.

FOR MORE INFORMATION

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